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Factors Affecting the Establishment of DIRECT-SEEDED PINE ON SURFACE-MINE SPOILS

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by William T. Plass

USDA FOREST SERVICE RESEARCH PAPER NE-290
1974

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MANUSCRIPT RECEIVED FOR PUBLICATION 7 SEPTEMBER 1973

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Factors Affecting the Establishment of
DIRECT-SEEDED PINE ON SURFACE-MINE SPOILS

Abstract

In a greenhouse study the emergence, survival, and growth of seven species of pine were related to chemical and textural characteristics of 12 Kentucky spoils. The results identify three factors that may affect the establishment of direct-seeded pine on surface-mine spoils. First, fine-textured spoil material may restrict seedling emergence. Coarse-textured sandstones and hard shales may provide a better seedbed. Second, species vary in their response to chemical and physical characteristics of the spoil material. Loblolly and longleaf pine were adapted to a wide range of spoils. The growth of shortleaf and white pine was reduced on extremely acid spoils.

Finally, the growth of loblolly pine was greatest where the percentage of phosphorus in the whole plant was greatest.

DIRECT SEEDING of pine is an appealing but as yet unreliable alternative method of spoil bank reforestation in the Appalachian region. Field trials have been made, but the results were not encouraging (*1, 2*).

On natural soils in the southern pine region, direct seeding on many sites is considered as reliable as planting. Guidelines for species selection, seed treatment, and site preparation are available (*3, 4*). Some of this information may apply to Appalachian surface-mine spoils. Additional information is needed to predict the effect of specific spoil characteristics on seedling establishment and growth.

The objective of this greenhouse study was to relate the emergence, survival, and growth of seven species of pine to chemical and textural characteristics of 12 spoils. The spoil characteristics considered are often used to identify those suitable for plant growth.

WHAT WE DID

Material from six eastern and six western Kentucky spoils was selected. These were mixtures of sandstones and shales in varying proportions. The pH of each spoil was determined in a laboratory with a standard line-operated pH meter and a 1:1 soil to distilled water solution. Spoil pH ranged from 2.5 to 8.4 (table 1). Plant-available phosphorus was determined on leachate extracted with Bray No. 1 solution. Available phosphorus ranged from 0.7 to 27.3 ppm.

Each of the 12 spoils was assigned to a redwood box measuring 11 by 18 inches, and 4½ inches deep. Before filling with spoil, each box was lined with black polyethylene. A ½-inch layer of perlite was placed at the bottom of each box to provide internal drainage. Next, a 1-inch layer of spoil was added. This spoil had been sieved through a ½-inch mesh screen. Seventy plant bands, measuring 1½ inches square and 3 inches deep, were placed in each box and half-filled with similar spoil. Half of the plant bands in each box were then filled with fine-textured material that passed a 20-mesh screen. The remainder of the bands in each box were filled with the coarse material that did not pass the 20-mesh screen. After each box was filled, it was brought to approximately 20 percent moisture by weight with distilled water.

Seven species of pine were sown. These represented northern and southern species that are recommended for spoil bank planting. The species were shortleaf pine (*Pinus echinata* Mill.), loblolly pine (*Pinus taeda* L.), Virginia pine (*Pinus virginiana* Mill.), longleaf pine (*Pinus palustris* Mill.), pitch pine (*Pinus rigida* Mill.), red pine (*Pinus resinosa* Ait.), and white pine (*Pinus strobus* L.).

Germination tests were run on one lot of 100 seeds of each species. The results at the end of 30 days were compared with the emergence in the spoil material. Emergence occurred when the hypocotyl arch broke through the surface of the spoil.

Table 1.—*The pH and plant-available phosphorus by spoils*

Number	Location	pH	Available phosphorus
			(ppm)
1	Western Kentucky	8.4	0.7
2	Western Kentucky	7.8	1.6
3	Western Kentucky	6.9	5.9
4	Eastern Kentucky	5.3	2.6
5	Eastern Kentucky	4.8	3.9
6	Eastern Kentucky	4.8	4.1
7	Eastern Kentucky	4.7	22.1
8	Western Kentucky	4.7	27.3
9	Eastern Kentucky	4.0	4.6
10	Eastern Kentucky	3.8	2.9
11	Western Kentucky	3.6	6.2
12	Western Kentucky	2.5	1.1

Ten plant bands in each box were assigned to each species. Half of these had been filled with fine-textured spoil, and the remainder with coarse-textured spoil. Ten seeds were placed in each plant band, and covered to a depth equal to the thickness of the seed.

Emergence and mortality were recorded for each plant band every 2 or 3 days. At the end of 120 days, the study was terminated. The spoil was washed from the roots, and each seedling was measured. Top length was measured to the nearest tenth of an inch from the root collar to the top of the terminal bud for all species except longleaf pine. Needle length was measured for longleaf pine due to its characteristic short stem development during the first growing season. Root length for all species was measured from the root collar to the tip of the longest primary root.

All loblolly pine seedlings on 10 of the spoils were oven dried and ground in a Wylie mill. This tissue, a composite of needles, stems, and roots, was analyzed spectrographically at a commercial laboratory to determine the concentration of the following nutrients: phosphorus, potassium, calcium, magnesium, manganese, iron aluminum, copper, zinc, boron, molybdenum, and sodium.

RESULTS

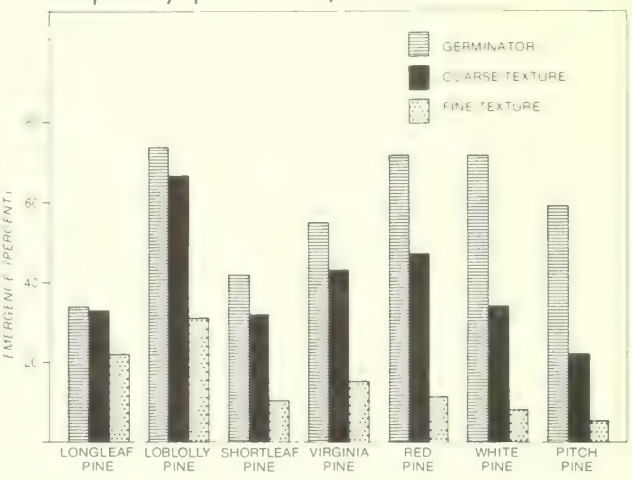
The success of direct seeding can be evaluated at three stages in seedling development: emergence, survival, and growth. Each of these in turn depends on different factors. In evaluating the results from this study, we considered species, spoil pH, and spoil texture. Species variations reflect inherent characteristics of the seed that may be difficult to manipulate. Spoil pH and spoil texture are external factors subject to modification by spoil treatments.

Emergence

The emergence of all species was strongly influenced by the extremes in spoil texture. For all species, emergence was significantly reduced in the fine material (fig. 1).

Spoil pH influenced emergence only on the extremely acid number 12 spoil. On this spoil, the species emerging were longleaf, loblolly, shortleaf, and Virginia pine. All seedlings were weak, and died soon after emergence.

Figure 1.—A comparison of germinator results with the percentage emergence at the end of 45 days on all spoils by species and spoil texture.



A factor contributing to the low emergence was soil crusting. Penetrometer tests after 1 day of drying indicated that forces of the magnitude of more than a ton per square foot were required to break through the crust. This may be particularly important for pine since germination is epigeous. The hypocotyl arch could experience difficulty in breaking through this hard material.

In the coarse-textured material, the emergence of longleaf and loblolly compared favorably with results in a germinator. Moderate differences between spoil and germinator occurred for shortleaf and Virginia pine, and large differences for white, red, and pitch pine. It is not known if the seed failed to germinate in the spoil, or if it germinated but did not emerge.

There were significant differences in seedling emergence between coarse- and fine-textured materials for 9 of the 12 spoils (fig. 2). These spoils ranged in pH from 3.8 to 8.4. Spoil texture did not affect emergence on spoils 8 and 11. On spoil 12, with a pH of 2.5, emergence was observed on the coarse-textured material, but not on the fine-textured material. Van Lear (5) has shown toxic ion concentration is greater on fine-textured spoil than on coarse-textured materials.

Figure 2.—Average percentage emergence at the end of 45 days for all species by spoil and spoil texture.

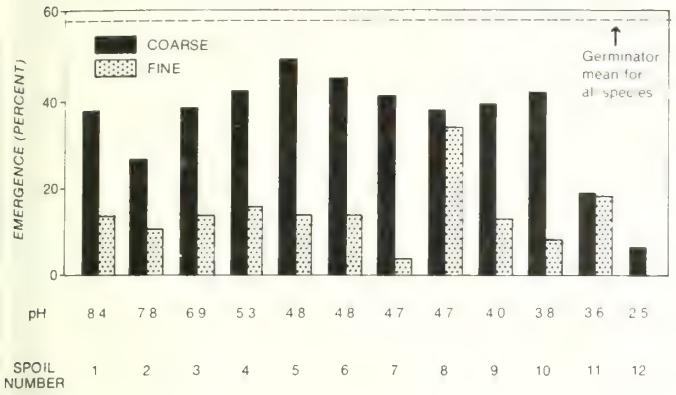
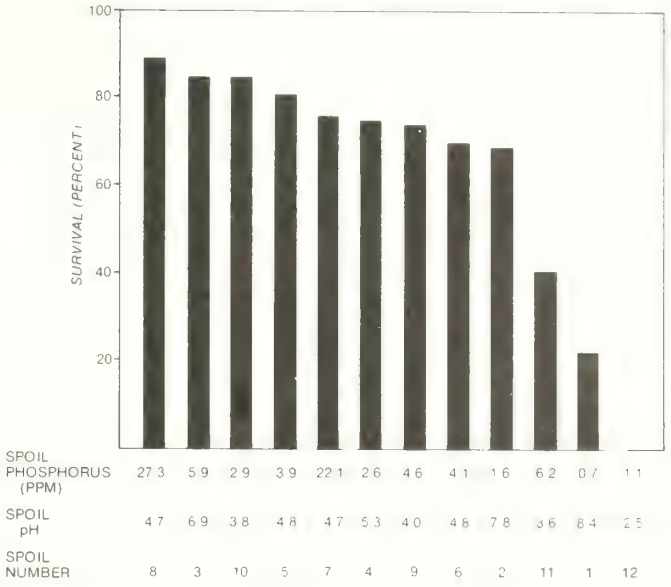

60
40
20
0
EMERGENCE (PERCENT)
COARSE
FINE
Germinator mean for all species
pH 8.4 7.8 6.9 5.3 4.8 4.8 4.7 4.7 4.0 3.8 3.6 2.5
SPOIL NUMBER 1 2 3 4 5 6 7 8 9 10 11 12

Figure 4.—Percentage survival by spoils for all species and both spoil textures.

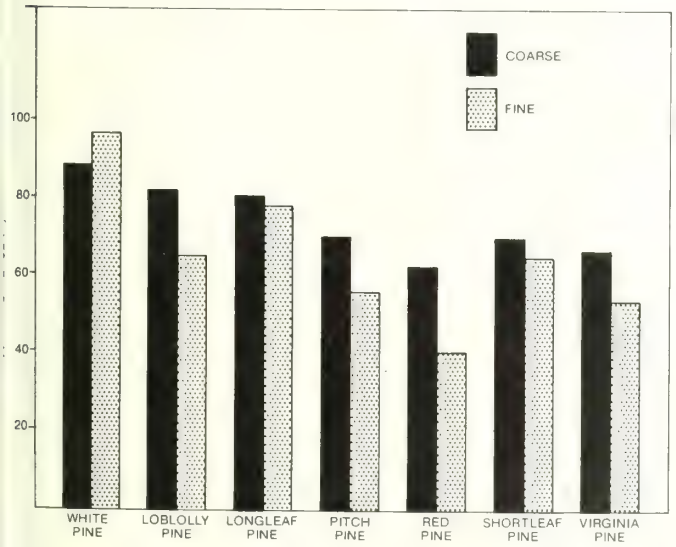


Survival

Textural classes did not significantly affect survival. White pine had the highest overall survival: 89 percent on the coarse material and 95 percent on the fine material (fig. 3). Red pine had the lowest survival: 65 percent on the coarse material and 40 percent on the fine material.

Survival for all emerging seedlings was similar on 9 of the 12 spoils (fig. 4). These varied widely in pH. Significantly lower survival occurred on spoils 11, 1, and 12 which had pH values of 3.6, 8.4, and 2.5, respectively.

Figure 3.—Percentage survival by species and spoil texture for all spoils.



Growth

On spoils where environmental conditions may be severe, or where there is a high risk of loss due to erosion, it seems reasonable to expect the largest seedlings to have the best chance of survival. This assumption considers the entire plant, since root development may be even more important than top growth.

Seedling growth differed between species, and varied with the chemical properties of the spoil. The effects of texture could not be evaluated since the roots of all species penetrated to depths below the surface textural extremes.

Loblolly and longleaf pine grew well on all spoils (table 2). Both species showed a tendency toward slower growth on spoils having a pH of 5.0 or higher. Longleaf pine needle length and loblolly pine root growth were significantly less on these spoils.

White pine, which characteristically makes slow initial growth, grew very slowly on all spoils and had the shortest mean root length of all species. Top and root growth were sig-

Table 2.—*Top and root growth for each species by spoil pH classes*

pH Class	Species						
	White pine	Red pine	Pitch pine	Virginia pine	Shortleaf pine	Loblolly pine	Longleaf pine
	(Inches)						
Top Growth:							
4.0 or less	1.4	1.4	1.8	2.6	2.1	4.1	11.7[a]
4.1 - 5.0	2.2	1.7	2.1	2.4	2.8	4.0	12.9[a]
5.1 or more	1.9	1.5	2.1	2.5	2.2	3.6	9.8[a]
Root Growth:							
4.0 or less	4.0	5.6	7.9	11.4	6.8	11.8	21.1
4.1 - 5.0	6.5	9.3	8.8	11.6	10.4	14.3	25.4
5.1 or more	5.9	9.2	9.2	10.2	8.2	9.8	23.7

[a]Needle length.

Table 3.—*Mean whole plant tissue analysis of loblolly pine seedlings from spoils supporting the best and poorest top growth*

Nutrient	A: Best growth[a]	B: Poorest growth[b]	A — B / B
Phosphorus, % O.D. Wt.	.180	.087	+ 107
Potassium, % O.D. Wt.	.853	.900	— 5
Calcium, % O.D. Wt.	.390	.633	— 38
Magnesium, % O.D. Wt.	.220	.253	— 13
Manganese, ppm	531.0	373.3	+ 42
Iron, ppm	1001.3	859.3	+ 17
Copper, ppm	19.0	23.0	— 17
Aluminum, ppm	2423.0	2204.0	+ 10
Zinc, ppm	69.0	86.3	— 20
Boron, ppm	20.7	19.3	+ 7
Molybdenum, ppm	1.883	2.017	— 7
Sodium, ppm	11.7	13.0	— 10

[a]Spoils: 5, 7, and 9
[b]Spoils: 3, 6, 10

Table 4.—*Mean whole plant tissue analysis of loblolly pine seedlings from spoils supporting the best and poorest root growth*

Nutrient	A: Best growth[a]	B: Poorest growth[b]	A — B / B
Phosphorus, % O.D. Wt.	.267	.087	+ 207
Potassium, % O.D. Wt.	.903	.863	+ 5
Calcium, % O.D. Wt.	.435	.383	+ 14
Magnesium, % O.D. Wt.	.210	.340	— 38
Manganese, ppm	617.7	510.3	+ 21
Iron, ppm	1372.0	1177.7	+ 16
Copper, ppm	20.0	30.7	— 35
Aluminum, ppm	2297.3	2213.0	+ 4
Zinc, ppm	73.7	63.0	+ 17
Boron, ppm	27.7	21.7	+ 28
Molybdenum, ppm	1.977	1.823	+ 8
Sodium, ppm	12.3	9.3	+ 43

[a]Spoils: 7, 8, and 9
[b]Spoils: 4, 10, and 11

nificantly reduced on spoils with a pH of 4.0 or less.

The greatest top and root growth for all species occurred on spoils with a pH between 4.1 and 5.0. Virginia pine was the species least affected by the chemistry of the spoil.

Tissue Analysis of Loblolly Pine

Composite samples of the needles, stem, and roots of loblolly pine seedlings were analyzed to relate growth to tissue analysis. Separate samples were collected for loblolly pine growing on 10 spoils. The analyses of seedlings from spoils supporting the best top growth were compared to analyses of seedlings from three spoils with the poorest top growth. Similar comparisons were made for seedlings from spoils supporting the best and poorest root growth.

In all comparisons, high tissue phosphorus was consistently related to better top and root growth (tables 3 and 4). Tissue of the larger seedlings had 2 to 3 times more phosphorus than the tissue of the small seedlings. Zarger considered phosphorus deficiency the primary limitation to tree growth on surface mine spoils (*6*).

Iron, manganese, copper, and boron were higher in seedlings growth on the spoils supporting better growth. Magnesium and copper were higher in seedlings making the poorest growth. There was no consistency for the other nutrients.

CONCLUSIONS

Several preliminary conclusions can be drawn from this data.

1. Spoils with a high percentage of fine-textured material probably should be avoided. Surface crusting of fine particles may interfere with emergence. Coarse-textured sandstones and hard shales appear to offer better seedbed conditions.

2. Species selection is important. For the seven species tested, longleaf and loblolly pine appear to offer the best opportunities for success. The inherent slow growth of white pine and its even slower growth on acid spoils could contribute to high mortality under field conditions.

3. Root growth was more responsive to the chemistry of the spoil than top growth, and it could be a critical factor in seedling survival. Sites with coarse-textured spoil with a pH between 4.1 and 5.0 may offer the best chance of success. Adequate available phosphorus is required for greatest root and top growth.

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The Effect of Monetary Incentives on Absenteeism: A Case Study

by Charles H. Wolf

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SEP 20 1974
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MANUSCRIPT RECEIVED FOR PUBLICATION 29 NOVEMBER 1973

ABSTRACT

An attendance bonus paid by a wood processing firm was studied to determine its effectiveness in reducing absenteeism. Employees were divided into permanent and short-term groups, and their response to the bonus was studied, using non-parametric tests. The evidence suggested that the incentive favorably influenced the work attendance of only the permanent group. Recommendations are made for future research.

ABSENTEEISM is a critical problem commonly encountered by management. In a survey of Missouri's wood industry, it ranked third in importance as a problem faced by supervisors in maintaining production (*Adair 1969*).

The effects of absenteeism can be measured in terms of higher production costs and lost sales. For example, consider:

Sick Pay.—Those who are absent are frequently given a half or even a full day's pay for which the company does not receive any work in return.

Other Fringe Benefits.—Even if sick pay is not given, most firms continue to contribute to the absentee's hospitalization and life insurance, and to provide the same number of paid holidays and vacation days.

Extra Workers on the Payroll.—Standby men, sometimes called "floaters", are often kept on the payroll to fill in for absentees. But since the number of absentees fluctuates, there are times when these extra men are not fully utilized.

Overtime Pay.—Firms are often forced to pay overtime premiums to make up for the lost production caused by absent workers.

Reduced Operating Efficiency.—When inexperienced workers are used as replacements for trained men, output is lower, raw material waste is frequently greater, and the end product is often poorer in quality.

Idle Machinery and Unused Investment.—This occurs when no one is available to take over the absentee's job.

Disrupted Schedules and Inconvenienced Customers.—Delays in production and shipping schedules may mean loss of customers to competitors, and the need to carry larger inventories.

Absenteeism can be classified as either voluntary or involuntary. Involuntary absences result from legitimate causes such as illness, death in one's family, jury duty, and injuries sustained on or off the job. In contrast, voluntary absenteeism is avoidable and can be prevented. It occurs when the employee could come to work but for some reason decides not to.

Two methods are often used to reduce and control voluntary absenteeism. The first method involves the use of various forms of punishment. An offending employee is usually given a warning, then is laid off, and is finally discharged if his absence from work continues. The threat of disciplinary action is used to coerce the employee into regular work attendance.

The second method consists of providing the employee with extra incentives for coming to work. These incentives may take the form of cash payments, additional time off, stock purchasing privileges, trading stamps, free lunches, or a chance at a company-sponsored jackpot.

Many managers object to the use of attendance incentives because they believe it should not be necessary to give extra compensation to employees for doing what they are expected and already paid to do. However, some companies that use attendance incentives claim that incentives are effective in reducing and controlling absenteeism.

To help determine the usefulness of incentive programs, we studied one being used by a wood processing firm in the Appalachian region.

BACKGROUND

The study firm operated two sawmills and a hardwood dimension plant which together employed 136 people. In December of 1970, the company's management started a cash incentive plan to encourage its non-supervisory production and maintenance workers to improve their work attendance.

The incentive plan was quite simple. Each individual who had worked a 5-day week received a $2 cash certificate that was re-

deemable once a year during the week before Christmas. The certificates were signed and distributed by the company's foremen at the end of each work week. Employees who were absent for more than 4 hours on any one day —regardless of the cause—did not receive their certificates.

The bonus represents 3.1 percent of the weekly pay for employees earning $1.60 per hour and 2.0 percent for those making $2.50 per hour. The first annual payment of the bonus was made in December of 1971 and amounted to nearly $5,000. Eight employees earned the maximum bonus of $104.

STUDY METHODS

To determine whether the incentive plan influenced work attendance, we examined absenteeism during three 6-month periods. The first period was from December 1969 through May 1970, during which there was no attendance bonus in effect. The second period was from December 1970 through May 1971. Because the bonus began in December 1970, its immediate effect was indicated during this period.

The third and final period was from December 1971 through May 1972, which immediately followed the company's first annual payment of the bonus. This period was examined to determine if employees improved their attendance after once having received a cash payment for their efforts.

Absenteeism for these three time periods was measured in two different ways. The first measure was the total number of days a worker was absent per period and the second was the number of incidents or occasions of absence per period. By using this latter measure, an employee who missed several consecutive workdays would be charged with only one incident of absenteeism. A measure of this type has been recommended for use as an indicator of voluntary absenteeism because it accounts for the frequency rather than the duration of absence (*Chadwick-Jones et al. 1971*).

The study firm's management felt that its permanent employees might be more responsive to the incentive than the workers with less tenure. To account for this possible difference, we divided the employees into permanent and short-term groups. Workers who had been continuously employed by the firm from December 1969 through May 1972 were classified as permanent employees. All others were placed in the short-term group.

Samples were randomly drawn from each of the employee groups. A sample of 27 men was selected from the permanent group. Three samples—30 men in each of the first two periods and 27 in the last—were selected from the short-term group.[1] It was necessary to draw an independent sample of short-term employees in each period because none of the men had worked all three periods.

Absence rates were found by making tabulations from employee time cards. All absences were counted with the exception of holidays and vacations. Employees were considered absent if they worked less than 4 hours during a regularly scheduled workday.

A plot of the data showed that the frequency distributions were skewed to the left and included a number of outliers. This suggested that a distribution-free or nonparametric test would be more appropriate than the analysis of variance. The signed-rank-difference test (*Wilcoxon 1949*) was used for permanent employees and the two-sample rank test (*Wilcoxon 1945*) was used for the short-term employees.

DISCUSSION AND RESULTS

Absenteeism for the firm's short-term employees was much greater than for the permanent ones (table 1). In 1970, the short-term men were absent 7 percent of the scheduled work time, as compared to only 4 percent for the permanent men. However, the average length of each incident of absence was longer for the permanent workers. In 1970, the permanent men were out of work an average of 2 days each time they were absent, while the short-term men were out of work only 1½ days. This probably indicates that a

[1]Thirty employees were originally included in each sample. During the final stages of data collection, a few were omitted because some of their time cards were missing.

Table 1.—*Mean absence per 100 working days for permanent and short-term employee samples*

Employee group	Absence measure	Operating period		
		1970[a]	1971[b]	1972[c]
Permanent	Number of days	3.99	4.38	2.56
	Number of incidents	2.04	2.31	1.65
Short-term	Number of days	6.98	8.81	7.91
	Number of incidents	4.77	5.88	5.20

[a]12/69-6/70 No incentive in effect.
[b]12/70-6/71 Incentive in effect but no cash yet received.
[c]12/71-6/72 Incentive in effect and cash received in December for 1971 attendance.

larger proportion of the absences of short-term men were voluntary.

The mean number of days absent increased from 1970 to 1971 and then decreased in 1972 for both the permanent and short-term employee samples. Analysis of variance indicated that these changes were not statistically significant at the 10 percent level for either days or incidents of absence and could easily have been the result of sampling.

The Wilcoxon signed-rank-difference test for the permanent employees provided evidence that the bonus was working. From 1970 to 1972, there was a decrease in the median number of days absent ($P=.046$). There was also weak evidence of a decrease in absences over time under the bonus except for incidents of absence during the 1970–71 period. The two-sample rank test showed no statistically significant difference in absenteeism of the short-term employees.

The evidence available indicates that the incentive plan favorably influenced the work attendance of the permanent employees but had no measurable effect on the short-term men. This conclusion supports management's prior observation that the permanent men were making an extra effort to get to work while there was no noticeable change in the habits of the short-term employees.

The incentive did not affect the work attendance of the short-term employees even though they had the highest absence rates. A possible explanation is that the attendance certificates were redeemable only in December of each year and only if the worker was currently employed by the firm. This restriction made many of the workers ineligible to receive the bonus, thereby taking away any incentive they might have had to improve their work attendance. This could have been partly avoided by making the payments on a quarterly or monthly basis. An alternative to increasing the frequency of payment would be to permit workers to redeem their certificates whenever they terminated their jobs or to sell them to other employees.

The 12-month waiting period required to redeem the attendance certificates may have been too long. To effectively motivate employees, incentives should be paid on a relatively frequent basis. Too long a time interval between payoffs may cause a loss of interest. In our opinion, a time interval of 3 months or less would be more suitable.

The size of the attendance incentive was relatively small compared to similar incentives that have been used by other companies. Most attendance incentive plans that have been reported in the literature provide a bonus representing 5 to 10 percent of an employee's weekly pay. A larger incentive by the study firm might have resulted in a greater response by all the employees.

In spite of these faults, the incentive plan had several good features. It was simple to explain and could be easily understood by the firm's employees. The plan treated all workers fairly and avoided arbitrarily determining whether each absence was justified. A half-day's absence was permitted without penalty. This helped to avoid the ill-will of employees who would have otherwise lost their bonuses for excusable reasons. And the plan was designed so as not to become too great a clerical and administrative burden.

The incentive plan might have caused a more impressive change in absenteeism if it had been introduced by a firm that originally had high absence rates. The absence rates of the study firm (4 percent for permanent men and 7 percent for short-term men) were relatively low compared with those of other lumber companies in the same area. During 1970 —the year before the incentive plan started

—two nearby firms lost twice as much time because of absenteeism. Many personnel managers consider between 2 to 3 percent to be the minimum rate obtainable.

RESEARCH NEEDS

This study has shown that additional research is needed before conclusions can be drawn about the usefulness of attendance incentives. Different forms of rewards—money, time off, stamps, etc.—need to be explored along with the effects of varying the size, frequency, and basis of payment. Positive incentives should be compared with disciplinary measures to determine which approach is most effective for reducing absenteeism. These studies should extend over several years to find out whether the effectiveness of incentives diminishes with time.

The incentive plan cost the company nearly $5,000 per year. It is uncertain whether the improvement in work attendance among the senior employees justified this outlay. Management did not know how much absenteeism was costing the company. Therefore, it was impossible to compare the cost of the incentive program with the savings from lower absenteeism.

This emphasizes the need to develop cost accounting procedures to determine the losses caused by absenteeism. Such procedures would enable managers to evaluate the economics of incentive schemes.

If at all possible, future studies of attendance incentive programs should include control groups. Other mills in the same company or separate departments and work shifts could serve this purpose, provided that both management and the employees are willing to cooperate.

All incentive plans have an important shortcoming—they fail to identify and correct the underlying causes of poor work attendance. For example, high absenteeism may be caused by poor working conditions or inadequate communication between supervisors and their men. Offering a pay incentive may tend to make the employees more tolerant of these conditions rather than correcting them. A better approach would be to accompany the incentive with management efforts aimed at improving the conditions that initially caused the absenteeism.

To do this, research is needed to identify and measure the personal, organizational, and labor market variables that influence absence rates. Included in these categories are such factors as age, occupation, tenure, firm size and industry, work schedules, sick leave policies, wages, and the unemployment rate. Studies of this type would provide information needed to design incentive programs and to suggest changes for eliminating some of the causes of absenteeism.

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A procedure for SELECTION MARKING in HARDWOODS

Combining silvicultural considerations with economic guidelines

by George R. Trimble, Jr.
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USDA FOREST SERVICE RESEARCH PAPER NE-292
1974

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MANUSCRIPT RECEIVED FOR PUBLICATION 22 JANUARY 1974

A procedure for SELECTION MARKING in HARDWOODS

ABSTRACT

This method of applying individual-tree selection silviculture to hardwood stands combines silvicultural considerations with financial maturity guidelines into a tree-marking system. To develop this system it was necessary to determine rates of return based on 4/4 lumber, for many of the important Appalachian species. Trees were viewed as capital investments that should be liquidated when they fail to yield an acceptable rate of return. Present values of sawlog-size trees were determined by species, size, and log grades. Future values—in 10 years—were based on growth rates and projected changes in log grade. Actual stumpage values were determined, working back from standard lumber prices by deducting conversion costs. The first consideration in appraising a stand for marking is to mark for removal the poor-quality, poor-risk, and short-lived trees, then mark the good trees according to their rate of return. Tree sizes to mark were established for 2-, 4-, and 6-percent return rates. Different rates were determined by site-quality classes. Guidelines were established for satisfactory residual basal areas, and examples are given of adjustments sometimes necessary in unmanaged stands where it may not be possible with the rate of return chosen to make a profitable cut and leave a satisfactorily stocked stand.

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Our purpose in this paper is to describe one method of applying individual-tree selection silviculture to hardwood stands. We do not deal with the advantages of even-aged versus uneven-aged systems; but, on the assumption that the decision has been made to practice individual tree-selection cutting, we outline a specific method of doing this. The reader should not expect to get from this discussion a rationale for the practice of one type of silvicultural system over others.

The selection system we propose incorporates economic guidelines for selecting trees to cut. These economic guidelines are in the form of rates of return for individual trees. In combination with the usual silvical considerations, they can be used to determine which tree should be cut.

Application of these marking guides is limited to sawtimber-size trees—stems above 11.0 inches dbh. Where markets permit cutting of smaller trees, considerations other than those outlined here must be used to indicate which stems to cut and which to leave.

The Need for Better Guidelines in Managing Stands by Selection Cutting

If an appreciable acreage of forest land is to be managed under an uneven-aged system employing selection cutting, then it is important that we concern ourselves with the guidelines we are going to use in applying this type of silviculture. Probably most foresters would agree that selection cutting in hardwoods in the past has often been on a "seat-of-the-pants" basis, generally without adequate consideration of residual stocking, distribution of stems by diameter classes, setting cutting cycles based on potential growth rates, log quality, or even provision for reproduction. Some good selection marking has been done, but much has been inadequate.

Probably the main reason why we have not concerned ourselves more with developing better guidelines for selection marking is the nature of the stands we have been working in. For the most part, we have been marking in unmanaged second-growth stands that contain a high proportion of poor stems, many of them old-growth residuals. It is often said that such stands "mark themselves".

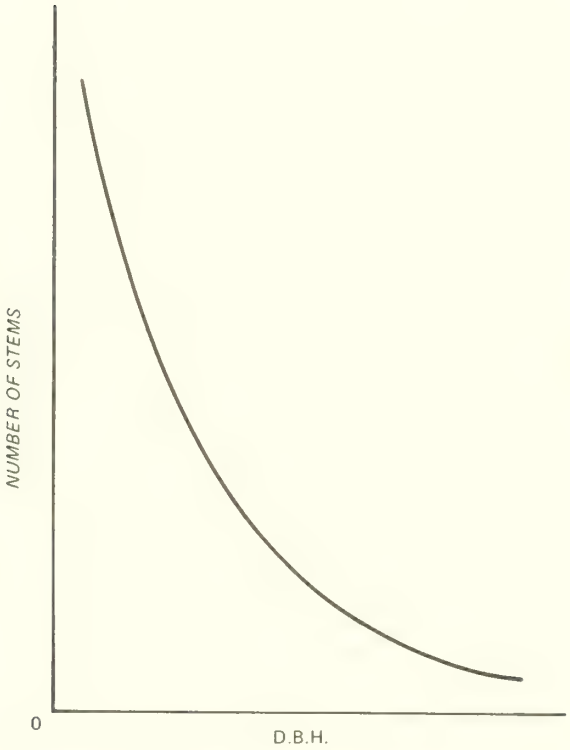
In these stands, the usual procedure has been to make an improvement cutting, combined with a thinning. All too often, the thinning has taken the form of a high-grading. Where the marking did not include too much high-grading, the stand was usually improved. However, we were not really practicing selection silviculture: we were just making a conditioning cut in an unmanaged stand, the type of cutting that could be followed by the imposition of either uneven-aged or even-aged systems.

We are now at the point where we are returning to many stands for subsequent cuttings. Many of these stands, conditioned by the first cuttings, are now ready for better planned marking. And many stands that we have not cut yet would benefit from a better planned initial cutting. This is especially true if we are to tailor our forestry more closely to specific goals.

None of this is to say that the selection system per se is new or that guidelines for its application do not exist. Selection silviculture has been applied for many years, and its principles have been reported voluminously in the literature. Guidelines covering both silvicultural and regulatory aspects of its application have been published for many timber types; many of these are recent and incorporate the latest research results.

It should be recognized that selection silviculture can be applied with many modifications. In managing forest stands under any of the modifications, however, certain procedures are implicit. Trees are designated for cutting—

Figure 1.—Schematic presentation of the typical inverted J-shaped curve illustrating the relationship between number of stems and dbh in an all-aged stand.



or for leaving—with the intention of retaining a residual stand adequately stocked for attainment of specific objectives, normally near maxium growth. Periods between cuts (cutting cycles) are based largely on growth rates. The poorer and less desirable stems are marked first for removal; so the stand is constantly upgraded. And often—particularly of late—a real attempt is made to mark through the range of merchantable diameters so as to leave a stand structure that will provide for adequate ingrowth from the lower diameter classes. The ideal structured stand has an inverted J-shaped curve when number of trees is plotted over dbh (fig.1).

Background Research on Rate of Return

In recent years, scientists of the Northeastern Forest Experiment Station have developed rate-of-return information for individual trees of the following hardwood species: northern red oak, white oak, and chestnut oak (*Trimble and Mendel 1969*); yellow-poplar and beech (*Mendel and Trimble 1969*); black cherry, red maple, and white ash (*Grisez and Mendel 1972*); and sugar maple (*Mendel, Grisez, and Trimble 1973*). This rate-of-return information was compiled for sawlog-size trees, based on a product common to each of the species—4/4 lumber. Similar information for pole-size trees or other products is not presently available.

Rate-of-return information is based on the financial-maturity concept, in which trees are viewed as capital investments that should be liquidated when they fail to yield an acceptable rate of return. Thus trees expected to exceed minimum acceptable return—because of rapid growth or quality improvement—should be left to grow, while those expected to fall below the minimum acceptable return are financially mature, and should be harvested.

To determine whether or not a tree was financially mature, we estimated its present value and its expected value 10 years in the future. Expected value is the present value plus the increase in value due to diameter growth, increase in volume, and improvement in quality over the next 10 years. The original value and the future value were then used to compute the compound interest rate of return.

Years of field work were required to determine growth rates of trees by species, vigor classes, and in some cases site quality. Additional research had to be done to determine log-grade changes by the same tree classes. Then tree values had to be determined, working back from standard lumber prices by deducting conversion costs. The methods used in arriving at rate of return and the data on which they were based are explained in the publications cited above.

Some of the findings of this work on rates of return are:

1. Rate of tree earning power in percent is less for trees of large diameter, even though actual dollar earning power will often be greater for the large trees.

2. Rate of earning power in percent is lower for trees of present high quality, even

though these trees may have higher dollar earnings.

3. Prospective earning power is greatly increased by potential improvement in tree quality.
4. Tree earning power increases markedly with increasing diameter growth rate.
5. Trees with greater merchantable height usually have slightly higher earning power.
6. Trees that increase in merchantable height have higher earning power—if the upper logs have positive values.

Items 1 and 2 above should not be interpreted as indicating that all large high-quality trees would be cut. It is true (table 1) that earning power is greater for smaller trees that have the potential for fast growth and quality improvement. However, the break-off point for even the highest rate of return, 6 percent, does not come until after the good trees have reached a minimum size to produce a grade-1 butt log. And as the desired rate of return drops, the dbh of the good trees to be retained in the stand increases.

The Development of Guidelines —A Combination of Theory and Practical Experience

The incorporation of rate-of-return information into a marking system for selection silviculture seemed particularly appropriate because the rates of return were based on individual stems. In this adaptation, it seemed best to think of the rates in terms of low, medium, and high returns rather than the absolute rates on which they are based (2, 4, and 6 percent). The primary reason for this is that the differences in prices and costs over time and from place to place can alter the actual rate of return.

It was realized that the use of rate-of-return guidelines alone for selection marking would be little better than marking for a refined diameter-limit cutting. The ideal procedure would be to integrate the concept of return into a system that was based primarily on sound silvicultural considerations, thus providing for a well-stocked high-quality residual stand. This seemed possible because financial maturity depends heavily on log quality and tree vigor.

With this in mind, we first developed a set of marking instructions based largely on silvicultural considerations. These were refined after considerable field testing. The following six classes of sawlog-size trees are suggested for removal for all rate-of-return classes and for all sites from fair to excellent:

1. Culls—marked for deadening.
2. Near-culls and trees with significant rot in the main stem.
3. Trees with butt-log grade of 5—local use logs.
4. Trees over 15 inches dbh with a butt-log grade of 4.
5. Trees of low vigor, including all overtopped trees of intolerant species.
6. Short-lived species such as black locust, sassafras, and butternut—unless they are unusually vigorous.

These then are the kinds of trees marked largely for silvicultural reasons.

But what about the good stems? How are they to be marked? The rate-of-return criteria apply to the vigorous and sound dominant and codominant trees—the crop trees. These trees will be left or cut depending on how well they meet the marker's objective in terms of the annual percentage return he sets as his goal for the next 10 years. Those that earn as much or more than the owner's expected return will be left to grow. Those that earn less will be taken. They would be financially mature. The rate-of-return marking guides were summarized from the publications cited previously (table 1). Trees equal to the dbh's shown and larger are to be marked for cutting *unless there is good prospect of a butt-log grade improvement in the next 10 years; in such cases they will be left.* The importance of log-grade improvement in increasing earning power should be stressed. As logs improve from one grade to another, their value jumps markedly.

The minimum dbh for a tree that can have a grade-1 butt log is 16 inches (grade 1 is the best sawlog grade). Because most trees below this size class that are good enough to leave under silvicultural considerations can improve in grade, the minimum dbh for removal under

the rate-of-return criteria was set at 17+ inches (minimum size for an 18-inch dbh class).

Site quality makes a difference in the financial maturity dbh of trees. On the better sites, where growth rates are higher, we can leave bigger trees for any given rate of return (table 1).

To prevent understocking a stand—an important consideration in marking for any selection cutting—the marker must set a residual basal-area goal in desirable trees above the sawlog threshold—11 inches dbh. When we talk about the stand in respect to understocking, we are referring to delineated areas receiving similar treatment and marked for cutting at one time, but not every ¼ acre or even every acre within the area. Some small patches may be heavily cut; others will hardly be touched.

Taking into account that 10 percent of the unmarked basal area may be lost to logging damage, the marking should be aimed at a residual basal area in sawtimber-size stems by site class as follows: Excellent site—70 to 85 square feet; good site—55 to 70 square feet; fair site—40 to 55 square feet. (We can assume 15 to 20 square feet in 5 to 11-inch poles for comparing these density figures to basal-area stocking guides developed for stands above 5 inches dbh.) In heavily stocked stands that have not been cut previously, the marker should strive for a residual basal area near the top of the range; in stands that have been cut at least once, he should aim for a basal area near the bottom of the range. Maintaining these residual basal areas should permit harvesting on a 10-year cutting cycle for excellent and good sites and in some situations for fair sites.

During the process of developing our marking guidelines, we field-tested our ideas as a standard procedure both on plots and on six large areas totalling about 300 acres where the marked trees were logged. This testing was done on the Fernow Experimental Forest in West Virginia in hardwood stands growing on areas of oak site indexes 80, 70, and 60 feet. We actually applied the following rates of return: 2, 4, 6, and 3 percent (we interpolated between the established 2 and 4 percent rates to get the dbh's for the 3-percent rate).

We believe that the marking method defined in this paper offers several advantages over customary marking techniques employed in all-aged silviculture.

First, it contains guidelines for more specific consideration of log quality as a factor in determining trees to cut and trees to leave. This is of vital concern in hardwood stands managed for sawlogs because in these stands log quality largely determines value.

Also, it specifically incorporates economic objectives—rate of return—without sacrificing silvical considerations.

Moreover, it is more easily applied than the classical method involving strict control of the number of trees by diameter classes.

Applicability

In appraising these guides to selection marking, a number of questions come to mind, questions that require answering if we are to apply the guides successfully:

1. Does this system of marking provide for regulation of cut—does it maintain an adequate stand structure for approximately equal cuts at fairly regular intervals?
2. Does this system provide for adequate regeneration?
3. What kind of knowledge and experience does the marker need?
4. What are the pitfalls of using this system, or in what types of stands is there a risk of failure?

Does this System of Marking Provide for Regulation of Cut—Does It Maintain an Adequate Stand Structure for Approximately Equal Cuts at Fairly Regular Intervals?

Obviously this system of marking does not provide for stand renewal by deliberately leaving a prescribed number of trees in each tree-size class, as does the more classical—and more complicated—method that tailors the residual stand to a predetermined diameter distribution. And so the system does not lend itself to as rigid control. But is its control potential adequate, and is stricter control necessary? We believe that, applied judiciously, the regulation potential of this system is adequate and that stricter control is not necessary.

First, we do not overcut the large trees in the stand—unless they are very poor. By large trees, we mean stems below but approaching financial maturity size. And if, as a first cutting in an unmanaged stand, we are forced to overcut these large stems because they are poor, we would be forced to do so regardless of the system of selection cutting. The result of this, in any case, is simply to delay the time when the stand is in equilibrium with the cutting method.

Next we remove the poor trees *throughout* the diameter range of sawtimber. In our mixed hardwood stands there will always be a number of such stems. Thus we will be providing growing space for better stems. As long as we do not understock the stand—and this is why residual-basal-area guides are necessary—we believe we will provide adequately for stand renewal, even though there are apt to be minor dbh gaps and surges. Therefore, following this method, we probably will not always be able to cut periodically the same volumes from trees of the same diameter classes.

Does the System Provide for Adequate Regeneration?

The work on individual-tree selection systems on the Fernow Experimental Forest, carried out for more than 20 years, shows definitely that we get adequate reproduction in number of stems, and that this reproduction develops. However, individual-tree selection cutting restricts the species composition of reproduction largely to the tolerants, such as the maples and beech. Diameter-limit cutting, on the other hand, because of its happenstance creation of small openings, results in the reproduction of a fair proportion of intolerants —but still a much lower proportion of these intolerants than does clearcutting or than might be desirable. Financial-maturity control, because cutting is determined in part by diameter, often results in the happenstance creation of openings suitable for the reproduction of intolerants. Thus we can expect this system to produce stands in which the proportion of intolerants is greater than in stands resulting from the usual single-tree selection marking.

What kind of knowledge and experience does the marker need?

1. The marker should be a forester experienced in the timber type—or a well-trained technician who can do the job with adequate guidance.
2. The marker should have a good working knowledge of log grades.
3. He should be able to recognize culls and serious defects.
4. He should be familiar with crown classes and indicators of tree vigor.

All the above qualifications are necessary to do a good job of selection marking under any set of guidelines.

5. Moreover, for this particular type of selection, the marker must know how to apply the rate-of-return guides.

In addition, the man who determines the rate-of-return guides to be used—whether or not he does the actual marking himself—must be able to: (1) Distinguish broad site classes, (2) recognize stand boundaries, and (3) have a good knowledge of markets in the area.

What are the pitfalls of using this system, or in what types of stands is there a risk of failure?

There are two main situations to watch out for: (1) The cutting should not appreciably understock the stand, and (2) the cutting in any given stand must—in most cases—assure a profitable harvest.

Whether or not a proposed cutting is merchantable depends on markets, amount and quality of products to be removed, and stand accessibility. These have to be appraised on the ground for each situation.

As with the application of any type of silviculture in the management of a stand, information is needed about the stand itself. If a good inventory is available, it is easy to decide whether or not a particular stand should be cut. In the absence of inventory data, cut-and-leave tally plots can be used to determine the feasibility of the proposed cutting or the necessity to adjust objectives to stand realities. A method of using cut-and-leave tally

plots as a basis for the type of selection marking proposed here is illustrated in appendix I.

We have, in the following, used a number of examples to illustrate the application and possible adjustment of the guidelines to specific situations. We realize that, in many stands (if not most), it is going to take time and several cutting cycles to bring the system and the stand into equilibrium; this would be true with any selection system.

The selection system with rate-of-return guides offers a flexibility that favors adjustment to pressures for management for other forest uses than timber. For example, to produce large trees for esthetic reasons, a manager of public forest land may elect to practice the selection system by using low (2 percent) rate-of-return guidelines. Thus he could meet his esthetic objectives, harvest timber products, and get needed stand improvement done. On the other hand, a grower of stumpage for profit would probably aim his marking at a high return level, say 6 percent.

In initiating management in unmanaged stands, it may not always be possible to choose a return level consistent with ownership objectives; it may be necessary to adjust the rate-of-return level to stand conditions. Take the case of an owner who wants to make 6 percent, but who has a middle-aged stand of trees on a good site with a high proportion of the overstory just above the cutting diameter for 6-percent return. If he simply followed the guides for 6 percent, he would drastically overcut the stand. But using our method, residual-basal-area per acre requirements would preclude his making such a cut. The logical procedure for him to follow would be to make the first cut, using guides for a lower rate of return, and work up through succeeding cuts to the 6-percent level.

The converse of this situation may also occur: an owner may want to grow big trees and may be satisfied with a 2-percent return. But suppose he needs a return now from his woodlot, and present stand conditions will not support a profitable cut if he follows the 2-percent guides? His solution may be to make a cut following the 4-percent guides the first time and get to the 2-percent level later on. Again, residual stocking requirements must be considered.

Other adjustments are possible within this system. The marker may leave several culls per acre for den trees; he may favor or discriminate against species, including certain species below the rate-of-return guideline dbh's to take advantage of an especially good market; he may mark on a silvicultural basis in the 5- to 11-inch diameter understory for a pulpwood harvest; and he would almost certainly elect to deaden pole-sized culls, even though not harvesting trees below the sawlog threshold.

As an extreme example of stretching the selection system to fit an inappropriate situation, take a well-stocked even-aged stand of 75-year-old yellow-poplar on a very good site. The stand would be lacking in sufficient reproduction and small stems to support repeated operational cuts on anything like equal cutting cycles until an understory of tolerant species could be developed and grow to merchantable size. This might take over 100 years of selection cutting.

Another situation where selection cutting does not fit, and where, if initiated, would take an unusually long time to mold a suitable stand, is the case of a decadent high-graded sawlog stand. This, of course, is a classic case for clearcutting.

Neither of the last two cases are appropriate for cutting under the selection system. And, although in the first example rate-of-return guides could be used as a rough diameter-limit guide, they would have no application at all in the second.

In many cases, the 10-year cutting cycle on which the computations of financial maturity were based is unrealistic. On fair sites—site index 60 for oak—board-foot growth rates may not be high enough to support profitable periodic cuts every 10 years. And in unmanaged stands on all sites the first cut may have to be so heavy because of the necessity of removing a lot of low-grade and cull material that it would not be feasible to return for another cut in 10 years. We should realize that when the 10-year cycle is exceeded, the percentage rates no longer apply: extending the cutting cycle reduces the rate of return. And this is another reason why we prefer to use the terms low, moderate, and high rates of return.

Another factor that warrants some consid-

eration is that the high dbh's shown for certain species under the 2-percent rate-of-return level are probably beyond average physiological maturity, and most of these large trees would be marked for silvicultural reasons before reaching these diameters. For example, few red maples will be found that are sound and vigorous at the sizes shown under the 2-percent rate-of-return level shown in table 1; that is, 32, 30, and 30 inches for site indexes 80, 70, and 60, respectively.

Summary

The need for better guidelines to practicing selection silviculture is stressed. A marking system that is based on silvical considerations, combined with economic goals, is described and justified. The marking system applies to the sawlog portion of the stand only, to those trees over 11.0 inches dbh.

The desirability of leaving an adequately stocked stand is discussed, and residual basal areas are suggested. Detailed instructions are given as to which individual trees to mark, based on tree characteristics, site quality, and owner's economic objective in terms of the desired rate of return.

Methods of adjusting the guidelines to actual stand conditions are illustrated.

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Appendix I

PROCEDURES FOR USE OF CUT-AND-LEAVE PLOT DATA TO DETERMINE FEASIBILITY OF STAND OPERATIONS

Table 2 shows how the per-acre tallies are summarized from the cut-and-leave field tally sheets. By species and dbh class, the number of trees, volumes, and basal areas are accumulated and shown on a per-acre basis for: the total stand, the stand marked under silvicultural considerations alone, and the residual stand (total stand minus silvicultural marking).

The next step is to use the residual-stand data to estimate the additional trees that would be marked under the different rate-of-return levels. This is done for a stand on a good site (site index 70 for oak), using table 1 as a guide. Volumes and basal areas are computed for the appropriate trees to be marked for each rate-of-return level—the 2-, 4-, and 6-percent levels from table 1. The dbh's to be marked for the 3- and 5-percent levels can be interpolated from this table (and are shown in the card—appendix II). These data are then summarized in table 3 as the basis for an appraisal of the stand situation. In this table, the total volume marked for any rate-of-return marking includes the volume marked under silvicultural considerations.

Table 1.—Mark trees of these 2-inch[1] dbh classes and larger

Species	Rate of return desired								
	2 percent			4 percent			6 percent		
	Site index for oak								
	80	70	60	80	70	60	80	70	60
Yellow-poplar	26	26	24	20	18	18	18	18	18
Beech	24	22	22	20	18	18	18	18	18
Black cherry	32	30	30	22	20	18	18	18	18
Red maple	32	30	30	22	22	18	18	18	18
White ash	30	28	28	22	20	18	18	18	18
Sugar maple	32	32	30	22	22	18	18	18	18
Red oak	26	26	24	22	22	20	20	18	18
White oak	24	22	20	20	18	18	18	18	18
Chestnut oak	24	24	22	20	18	18	18	18	18
Other long-lived species[2]	26	26	24	20	20	18	18	18	18

[1] Two-inch dbh classes as follows: 18 inches (over 17 to 19 inches), 20 inches (19 to 21), etc.

[2] Not determined by research but set subjectively.

Table 2.—Per acre summary of cut-and-leave tally plots—excluding culls

[Site index of area: 70 (a good site)]

Species	Number of trees and board-foot volume by dbh classes																						
	12		14		16		18		20		22		24		26		28		30		Total		
	No.	Vol.	No.	Vol	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Volume	B.A.
TOTAL STAND																							
Red oak	5.5	352	7.1	1,015	5.2	1,139	4.1	1,214	2.4	895	1.2	540	0.7	369	0.3	181	0.2	136			26.7	5,841	
Chestnut oak	.1	6	.2	29																	.3	35	
Yellow-poplar	.8	78	1.0	192	1.2	343	1.4	532	.5	237	.3	170	.1	66							5.3	1,618	
Beech	.4	32	.2	28			.1	27	.1	33											.8	120	
Black cherry	1.4	111	1.6	258	1.4	340	1.2	391	.5	204	.2	98	.1	57							6.4	1,459	
Red maple	1.2	72	.4	56	.1	22	.1	30	.1	38											1.9	218	
White ash	.8	64	.5	83	.2	50	.1	34	.1	42											1.7	273	
Sugar maple	1.8	85	.6	77	.4	85	.1	29	.1	38	.3	138	.4	216	.1	62	.1	71			3.9	801	
Hickory	.7	65	.4	72	.1	26	.2	70													1.4	233	
Sweet birch	.5	32	.1	13																	.6	45	
Cucumbertree	.9	88	.3	58	.1	29	.1	38	.1	47											1.5	260	
Fraser magnolia	.4	26																			.4	26	
Black locust	.3	19																			.3	19	
Basswood	3.1	363	2.8	524	1.5	386	.7	228	.3	119	.1	47									8.5	1,667	
Total	17.9	1,393	15.2	2,405	10.2	2,420	8.1	2,593	4.2	1,653	2.1	993	1.3	708	0.4	243	0.3	207			59.7	12,615	80.4
STAND MARKED UNDER SILVICULTURAL CONSIDERATIONS																							
Red oak	1.2	77	1.2	172	0.1	22	0.2	59	0.1	37											2.8	367	
Chestnut oak			.1	14																	.1	14	
Yellow-poplar	.4	39	.1	19					.1	47											.6	105	
Beech	.3	24					.1	27	.1	33											.5	84	
Black cherry	.2	16	.2	32	.1	24			.1	41											.6	113	
Red maple	.2	12	.1	14					.1	38											.4	64	
White ash	.1	8			.1	25															.2	33	
Sugar maple	.4	19	.1	13							0.2	92	0.1	54			0.1	71			.9	249	
Hickory	.2	19			.1	26															.3	45	
Sweet birch	.4	26																			.4	26	
Cucumbertree	.7	69					.1	38	.1	47											.9	154	
Fraser magnolia	.4	26																			.4	26	
Black locust	.3	19																			.3	19	
Basswood	.1	12	.1	19	1.3	334	.2	65	.2	79											1.9	509	
Total	4.9	366	1.9	283	1.7	431	0.6	189	0.8	322	0.2	92	0.1	54			0.1	71			10.3	1,808	12.3

TOTAL STAND MINUS SILVICULTURAL MARKING

| | | |

Appendix II

Mark trees of these dbh classes and larger:

Species	Low						Medium						High		
	2%			3%			4%			5%			6%		
	80	70	60	80	70	60	80	70	60	80	70	60	80	70	60
Yellow-poplar	26	26	24	24	22	22	20	18	18	20	18	18	18	18	18
Beech	24	22	22	22	20	20	20	18	18	20	18	18	18	18	18
Black cherry	32	30	30	28	26	24	22	20	18	20	20	18	18	18	18
Red maple	32	30	30	28	26	24	22	22	18	20	20	18	18	18	18
White ash	30	28	28	26	24	24	22	20	18	20	20	18	18	18	18
Sugar maple	32	32	30	28	28	24	22	22	18	20	20	18	18	18	18
Red oak	26	26	24	24	24	22	22	22	20	22	20	20	20	18	18
White oak	24	22	20	22	20	20	20	18	18	20	18	18	18	18	18
Chestnut oak	24	24	22	22	22	20	20	18	18	20	18	18	18	18	18
Other long-lived species	26	26	24	24	24	22	20	20	18	20	20	18	18	18	18

TREES TO MARK—SAWLOG SIZES
(above 11.0 inches dbh)

For All Rate-of-Return Classes, Mark:

1. Culls and near culls.
2. Trees with significant rot in the butt log.
3. Very-low-vigor trees (vigor 4).
4. Extremely rough trees with butt-log grade 5.
5. Any trees over 15 inches with butt-log grade 4.
6. Any short-lived species, such as black locust, sassafras, and butternut, unless they are unusually vigorous.

In addition, trees above a certain dbh class are marked under certain conditions. This dbh varies with the rate of return desired, by species, and in the case of oak by site quality. It also varies by crown or vigor class and is additionally affected by the likelihood of log-grade improvement. The trees to mark are those of the indicated dbh's and larger. These will be marked unless a potential grade improvement can be foreseen in the next 10 years.

For the convenience of the reader, this information is also provided on a pocket-size card inserted loosely inside the front cover.

Appendix III

Common and scientific names of species referred to in this study:

Ash, white	*Fraxinus americana* L.
Basswood	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Butternut	*Juglans cinerea* L.
Cherry, black	*Prunus serotina* Ehrh.
Cucumbertree	*Magnolia acuminata* L.
Hickory	*Carya* spp.
Locust, black	*Robinia pseudoacacia* L.
Magnolia, Fraser	*Magnolia fraseri* Walt.
Maple, red	*Acer rubrum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, chestnut	*Quercus prinus* L.
Oak, northern red	*Quercus rubra* L.
Oak, white	*Quercus alba* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Yellow-poplar	*Liriodendron tulipifera* L.

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Recreation, Resources, and Right Decisions

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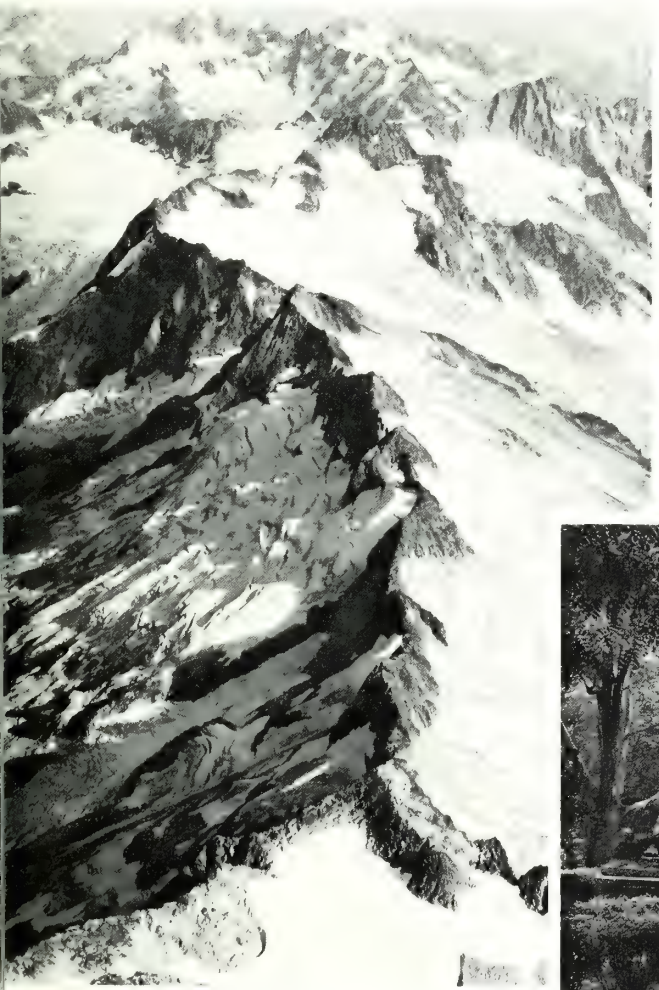

USDA FOREST SERVICE RESEARCH PAPER NE-293
1974

NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

ABSTRACT

In the midst of national concern for preserving ecosystems, stimulating the economy, and providing outdoor recreation opportunities for the American public, the modern recreation-resource decision-maker faces a monumental task. The authors present a series of relevance trees that pinpoint, in terms of interacting social and physical site variables, the important priorities in today's urban, rural, and wildland resource-management decisions. The results of this research provide a fairly simple structure for recreation managers to assess the effect of present and future social and political conditions on recreation planning and development decisions.

KEYWORDS: RECREATION, DECISIONS, URBAN, RURAL, WILDLANDS.

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MANUSCRIPT RECEIVED FOR PUBLICATION 4 MARCH 1974

IN THE MIDST of national concern for preserving ecosystems, stimulating the economy, and providing outdoor recreation opportunities for the American public, the modern recreation-resource decision-maker faces a monumental task. In this paper we present a series of *relevance trees* that pinpoint, in terms of interacting social and physical site variables, the important priorities in today's urban, rural, and wildland resource-management decisions.

Several years ago, a forecasting technique called PATTERN (Planning Assistance through Technical Evaluation of Relevance Numbers) was developed to help corporate decision-makers evaluate their decision-making (*Esch 1969*). Based on requirement- or need-oriented *relevance trees*, the methodology of PATTERN is flexible enough so that it can be applied to almost any situation where decisions must be made under conditions of uncertainty.

We have applied the PATTERN methodology to quantify some of the priorities that decision-makers assign to various social and physical factors in allocating and developing recreation resources for urban, rural, and wildland environments. Results of this research provide a fairly simple structure by use of which recreation managers can assess the effects of present and future social and political conditions on recreation planning and development decisions.

THE STUDY

We interviewed 47 decision-makers in four public agencies (table 1) about three decision situations:

1. Development of a typical 30-acre day-use recreation area in an urban environment.

2. Development of a typical 400-acre day-use recreation and overnight-use (camping) area in a rural forested enviroment.

3. Development of a 20,000-acre wildland recreation area with facilities such as hiking trails and canoe routes.

Table 1.—Agencies and number of top-level decision-makers interviewed about three recreation-management decisions

Agency	Number of people interviewed	Primary planning and development responsibility of agency
Bureau of Outdoor Recreation, Northeast Regional Office, Philadelphia, Pa.	18	Outdoor recreation in urban natural areas throughout the Northeastern States.
New York State Office of Planning Coordination, Albany, N. Y.	14	All types of planning and development activities throughout New York State, together with the relationships of state activities to federal and other governments.
Pennsylvania Bureau of State Parks, Harrisburg, Pa.	7	Recreation in natural areas throughout Pennsylvania.
United States Department of Agriculture, Forest Service, Washington, D. C.	8	Multiple-use forest management, including recreation throughout the Nation.
Total	47	

These decision-makers were on the staff of the chief executive of each agency. We asked them how they perceived certain priorities in urban-recreation development situations. We also asked urban-recreation decision-makers how they felt about selected items in forest-recreation development situations.

Social Factors Considered

For each of the three decision situations, the decision-makers were asked to assign priority values to 120 possible combinations of 12 social factors and 10 physical factors. These are the factors that most often influence one or more of the three decisions (tables 2 and 3). They were selected on the basis of preliminary discussions with decision-makers in the agencies studied.

Among the social factors that influence overall recreation demand and were used in this study were: *present recreation demand*, *expected similar future recreation demand*, *changing recreation demand patterns*, and *technological advances* related to demand.

The tangible and intangible social values considered were : *compatibility* of the recreation development with non-recreation uses, impact of the recreation development on *regional economies*, and impact of the development on *amenity values*.

Internal and external agency pressures that often influence recreation management decisions were considered in these factors: *money available*, *political influences*, *pressure groups*, and *interagency coordination* (table 2).

Physical Factors Considered

Physical factors associated with accessibility of a development were: *ease of access* and *distance from population* centers.

Factors of the physical resource were: *acreage* of the area to be developed, buildings and other *existing man-made structures*, *water-resource* development opportunities, *topography*, *natural vegetation*, *fish and wildlife* resources, and *uniqueness* of the area. This uniqueness factor is tied closely to the social factor called *amenity values* (table 3).

Interviews

The decision-makers were asked to quantitatively describe the relative importance of the social and physical factors in each of the three decision situations.

The interview form, the relevance-tree, was a two-dimensional matrix that contained the 10 physical factors and 12 social factors. Each of the 47 respondents completed a separate relevance tree for each of the three decisions. They were asked to assign a number between zero and 100 percent to show the importance that they attached to each of the social and physical factors in each decision.

Table 2.—Social factors considered by decision-makers in each of three decisions and examples of the kinds of activities, facilities, or environmental changes involved

Social factors	Definition	Examples		
		Decision 1: an urban recreation environment	Decision 2: a rural recreation environment	Decision 3: a wildland recreation environment
OVERALL RECREATION DEMAND				
Present demand	The area's capability to meet present consumption for the type of recreation facilities being planned.	Leisurely strolls. Swimming pools. Playgrounds.	Lake swimming. Picnicking. Camping.	Canoe portages. Mountain-climbing. Backpacking in roadless areas.
Similar future demand	The area's capability to meet expected future consumption for the type of recreation facilities being planned.	Leisurely strolls. Swimming pools. Playgrounds.	Lake swimming. Picnicking. Camping.	Canoe portages. Mountain-climbing. Backpacking in trailess areas.
Changing demand patterns	The area's capability to meet possible shifts in future consumption caused by relatively new types of recreation activities and facilities.	Open park zoos. City rooftops with vegetation and shallow pools for birds and marine life. Terraced buildings with a series of setbacks for sunlight, and planted with lawns, flowers, shrubs, and small trees.	Snowmobiles. Motor bikes. Skin-diving.	Monorail observation trips through natural areas. Disneyland type developments. Introduction of new big-game species.
Recreation-related technological advances	Scientific breakthroughs in recreational equipment design and environmental control.	Elimination of car traffic in cities. Air- and water-pollution control. Enclosed parks that maintain summer environment throughout the year.	New types of underwater recreation equipment. Combination boat-trailer camping equipment. New strains of bacteria that completely eliminate human waste in outdoor toilets.	One-man jet backpacks. Noiseless motors for boats and trail bikes. Three-dimensional wall-sized home televisions for viewing trips through wildland areas.
TANGIBLE AND INTANGIBLE SOCIAL VALUES				
Compatibility with non-recreation uses	Interaction of the recreation development with other land uses on or surrounding the recreation area.	Transportation systems. Commercial enterprises surrounding the area. Industrial development and expansion plans nearby.	Agricultural land use. Highway systems. Suburban expansion.	Timber and watershed management. Flooding land for power projects. Range management.

CONTINUED

Table 2.—Continued

Social factors	Definition	Examples		
		Decision 1: an urban recreation environment	Decision 2: a rural recreation environment	Decision 3: a wildland recreation environment
Regional economies	Impact of the recreation development on local and regional economies.	Present and potential opportunities for public and private capital investments in complementary recreation developments. Average annual income in the surrounding area. Influence on industry.		
Amenities	Effects of the recreation development on amenity values.	Landscaping. Distinguished buildings nearby. Art in the streets.	Climatologically pleasant surroundings. Unpolluted streams and lakes. Aesthetic, intangible values of the natural resource.	
		INTERNAL AND EXTERNAL AGENCY PRESSURES		
Money available	Budgetary constraints on recreation site planning and development goals.	Money allocated through public appropriations for development of recreation facilities.		
Political influences	Constraints emanating from executive, judicial, or legislative branches of government.	Social-welfare programs to provide better recreation facilities for the urban disadvantaged. Changes in administration.	Local government pressures to develop parks on the fringes of suburb. Political programs to stimulate the rural economy. Job opportunities for political appointees.	Legislative changes in resource-management practices. Laws governing allocation of forest-management areas to wilderness status. Articles written by legislators on wildland management.
Pressure groups	Influences resulting from organized recreation or resource-orientated pressure groups, other than state or federal.	Women's flower clubs. Men's civic groups. Institutional recreation groups.	Hunting and fishing clubs. Real estate companies. Public-utility development programs.	Wilderness organizations. Organizations representing surface and mineral interests. Groups and organizations concerned with air and water pollution and scenic beauty.
Interagency coordination	Public and private recreation administration agencies or organizations dealing with similar resources.	Agencies involved in the study defined the particular agencies they need to consider in each decision situation.		
		OTHER		
Other social factors	Decision-makers listed any other social factor that is important to consider in the particular decision.	Determined separately for each decision situation.		

Table 3.—Physical factors considered by decision-makers in each of three decisions and examples of the elements involved

Physical Factors	Definition	Examples		
		Decision 1: an urban recreation environment	Decision 2: a rural recreation environment	Decision 3: a wildland recreation environment
		RESOURCE ACCESSIBILITY		
Ease of access	The ease of access afforded by transportation systems to the area.	Subways. Bus lines. City streets.	Rural highways. Bus lines. Water routes.	Airlines. Interstate highways. Trails.
Distance from population centers	Physical distance from population centers.	Distance in miles.		
		RESOURCE CHARACTERISTICS		
Acreage	Size of area to be developed.	An average acreage was specified for each decision. Respondents were asked to restrict their evaluation of this factor to an "average" acreage figure because of the wide range of values that often exists around this average.		
Existing man-made structures	Buildings or facilities on the area to be developed.	Apartments. Commercial facilities. Cultural centers.	Old mills. Canal systems. Road networks.	Logging roads. Ghost towns. Forts.
Water resource	Existing and potential water-recreation resource opportunities	Ponds. Rivers. Water systems for fountains.	Existing dams. Water quality and underground water supply. Lake deep enough for water sports.	Waterfalls. Marshes. Secluded lakes.
Topography	Topography in and around the recreation area to be developed.	Level ground for playgrounds. Gentle slopes. Slow water currents.	Drainage for sewer systems. Adequate level areas for campsites. Sloping shoreline for beaches.	Number of mountain peaks. Variation in slopes. Landslide and avalanche potentials.

CONTINUED

Table 3.—Continued

Physical Factors	Definition	Examples		
		Decision 1: an urban recreation environment	Decision 2: a rural recreation environment	Decision 3: a wildland recreation environment
Natural vegetation	Diversity, amount, and distribution of natural vegetation in the area to be developed.	Pollution-resistant vegetation. Large trees that should be protected during development of the area. Vegetation needed to complement existing vegetation.	Wind-resistant trees in campgrounds and picnic areas. Vegetation to screen campgrounds. Fall coloration potential	Areas above timber line protected by ground cover to prevent erosion. Variability in timber size and distribution to provide maximum scenic quality. Enough ground vegetation to attract wildlife and also to afford adequate reproduction for future forests.
Fish and wildlife	Number and variety of fish and wildlife that are or could be introduced in the area to be developed.	Bird life. Stock water for fishing derbies. Den trees for squirrels.	Wildlife-viewing areas. Protecting people from bears. Fishing potential.	Hunting potential. Game preserves and flyway habitat. Fish stocking.
Uniqueness	Overall rarity value of the total resource before and after it is developed or preserved.	The *number* and *location* of similar areas already in existence or that could be developed in relation to the location of the present facility being planned.		
		OTHER		
Other physical factors	Decision-makers listed any other physical factors that are important in a particular decision.	Determined separately for each decision situation.		

Table 4.—An example of how relevance-tree data were recorded and adjusted

[In this example, only a few factors are included in a situation where the respondent chose to start with the social factors. Therefore, social factors are assigned first level scores and physical factors are assigned second level scores]

		Physical factors						
	Social Factors	Acreage		Water resources		Natural vegetation		Totals
0.70	Similar future demand	0.50	+	0.30	+	0.20	=	1.00
+								
.20	Money available	.30	+	.30	+	.40	=	1.00
+								
.10	Political influences	.70	+	.20	+	.10	=	1.00
1.00	Total							
	ADJUSTED DATA—FIRST X SECOND LEVEL SCORES							
	Similar future demand	0.35	+	0.21	+	0.14	=	0.70
	Money available	.06	+	.06	+	.08	=	.20
	Political influences	.07	+	.02	+	.01	=	.10
	Totals	0.48		0.29		0.23		1.00

The interviews were conducted in two stages. In stage one, a respondent was given a choice of which factor categories—social or physical—he wanted to consider *first*. Two relevance-tree forms were available. Form 1 listed the 12 social factors along the left-hand margin and the 10 physical factors across the top. Form 2 was arranged just the opposite. If a respondent wanted to consider social factors first, form 1 was used; if physical factors, form 2.

The factors in the left-hand margin of the form were designated as *first-level* relevance scores. The sum of the first-level scores that a respondent assigned was required to be 100 percent (table 4).

In stage two, each respondent was asked to consider the factors that were not chosen initially and to record the relative weights (second-level scores) that they felt each of the remaining factors should have *within the bounds or constraints of each of the first-level factors.* The sum of these second-level scores in any one row was required to be 100 percent (table 4).

The respondents were asked to complete the three relevance-tree forms at their convenience and to mail them back. However, as one top administrator pointed out, even this attempt to allow complete privacy when filling out the relevance trees may not alleviate the respondent's need to justify his reaction to each decision situation. To assure autonomous responses, the respondents were asked not to identify themselves on the survey forms.

Average Relevance Tree For Each Decision

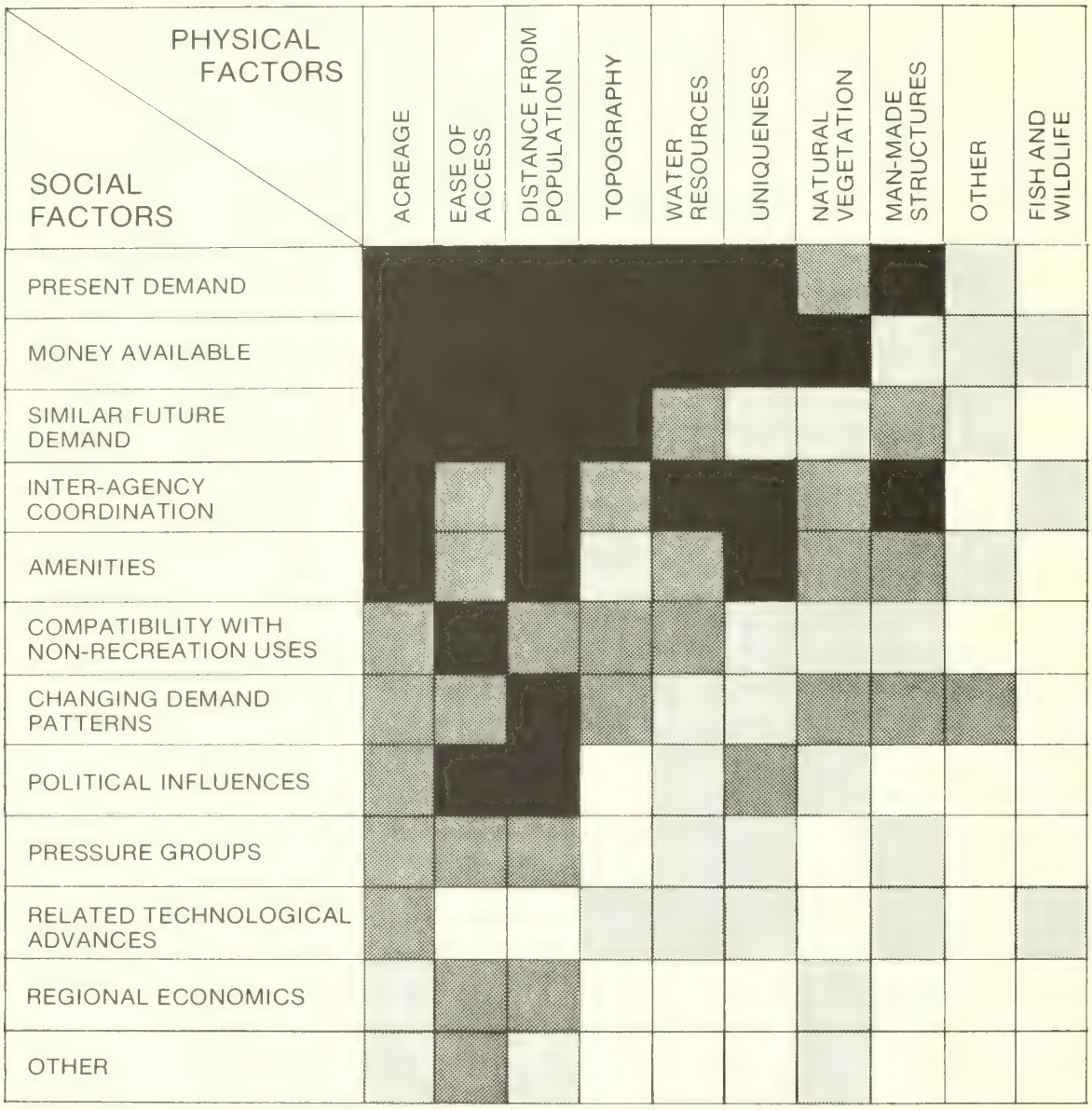
The relevance numbers entered by a respondent in the social and physical categories of a relevance tree were designated as *first-* or *second*-level scores according to their order of entry, as explained previously.

For each relevance tree, all second-level scores in the row adjacent to a given first-level category were multiplied by that first-level category score. This procedure *adjusted* all second-level scores throughout the relevance tree so the total of 120 cells equaled 100 percent (table 4).

The percentage values within any one adjusted relevance tree ranged from 0.000 to 0.045. Relevance-tree data were averaged for each of the three decisions within and across

Text continued on page 14.

Figure 1.—Decision one: average relative importance given 120 social-physical factors in decision-making by four agencies.



QUARTILE:	UPPER	UPPER MIDDLE	LOWER MIDDLE	LOWER
SUM OF THE 30 PERCENTAGES WITHIN EACH QUARTILE	54	27	14	5
RANGE OF PERCENTAGES WITHIN EACH QUARTILE	.04482 → .01182	.01166 → .0070	.0069 → .0029	.0028 → .0002

Figure 2.—Decision one: social and physical decision factors arranged by average order of priority for all four agencies combined. Percentage under each bar indicates the priority value or the relative importance of each factor in influencing the final decision. Average response for each agency is plotted around the overall average trend.

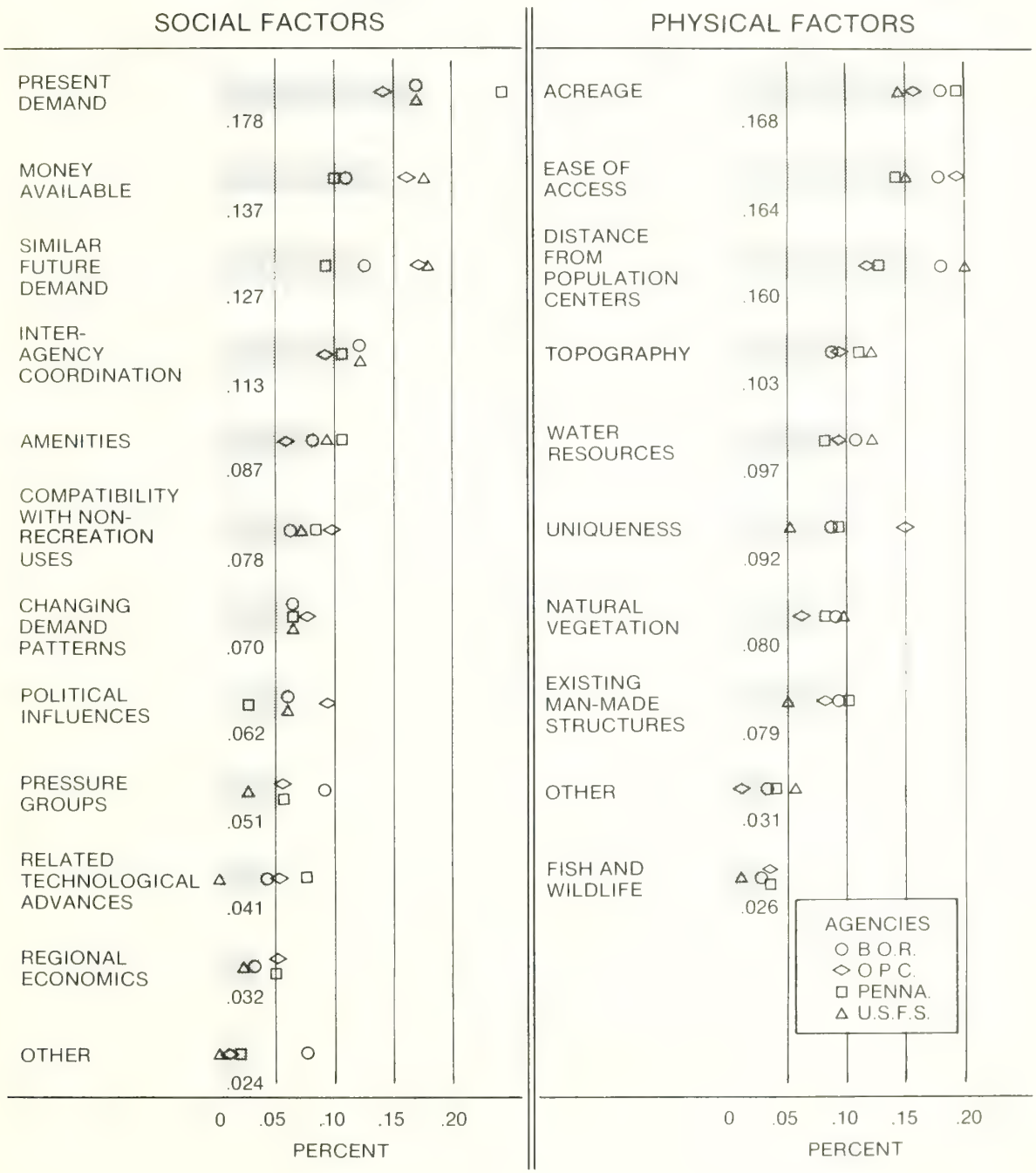
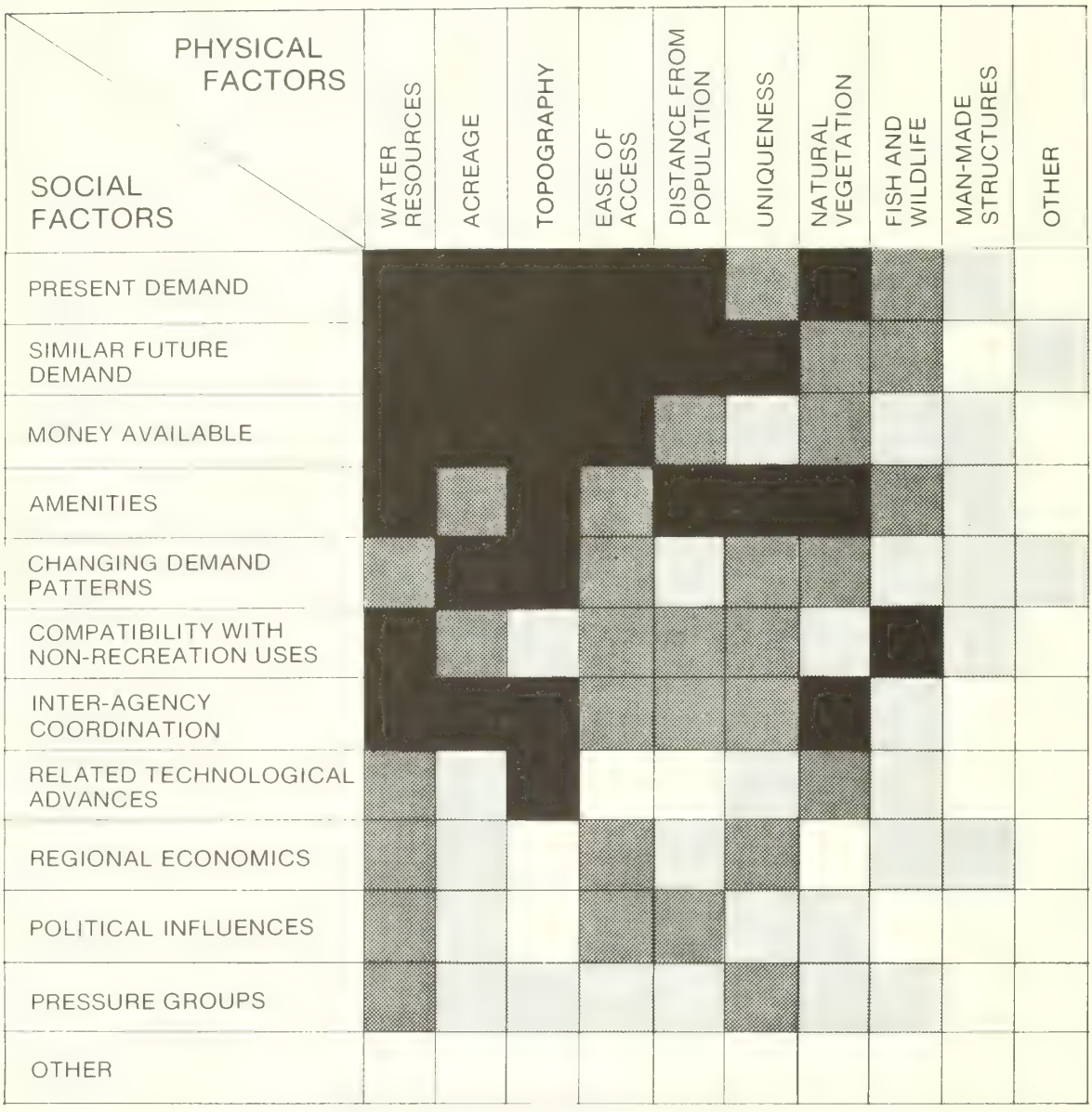


Figure 3.—Decision two: average relative importance given 120 social-physical factors in decision-making by four agencies.



QUARTILE:	UPPER	UPPER MIDDLE	LOWER MIDDLE	LOWER
SUM OF THE 30 PERCENTAGES WITHIN EACH QUARTILE	50	28	17	5
RANGE OF PERCENTAGES WITHIN EACH QUARTILE	.0272→.0116	.0113→.0080	.0076→.0038	.0037→.0000

Figure 4.—Decision two: social and physical decision factors arranged by average order of priority for all four agencies combined.

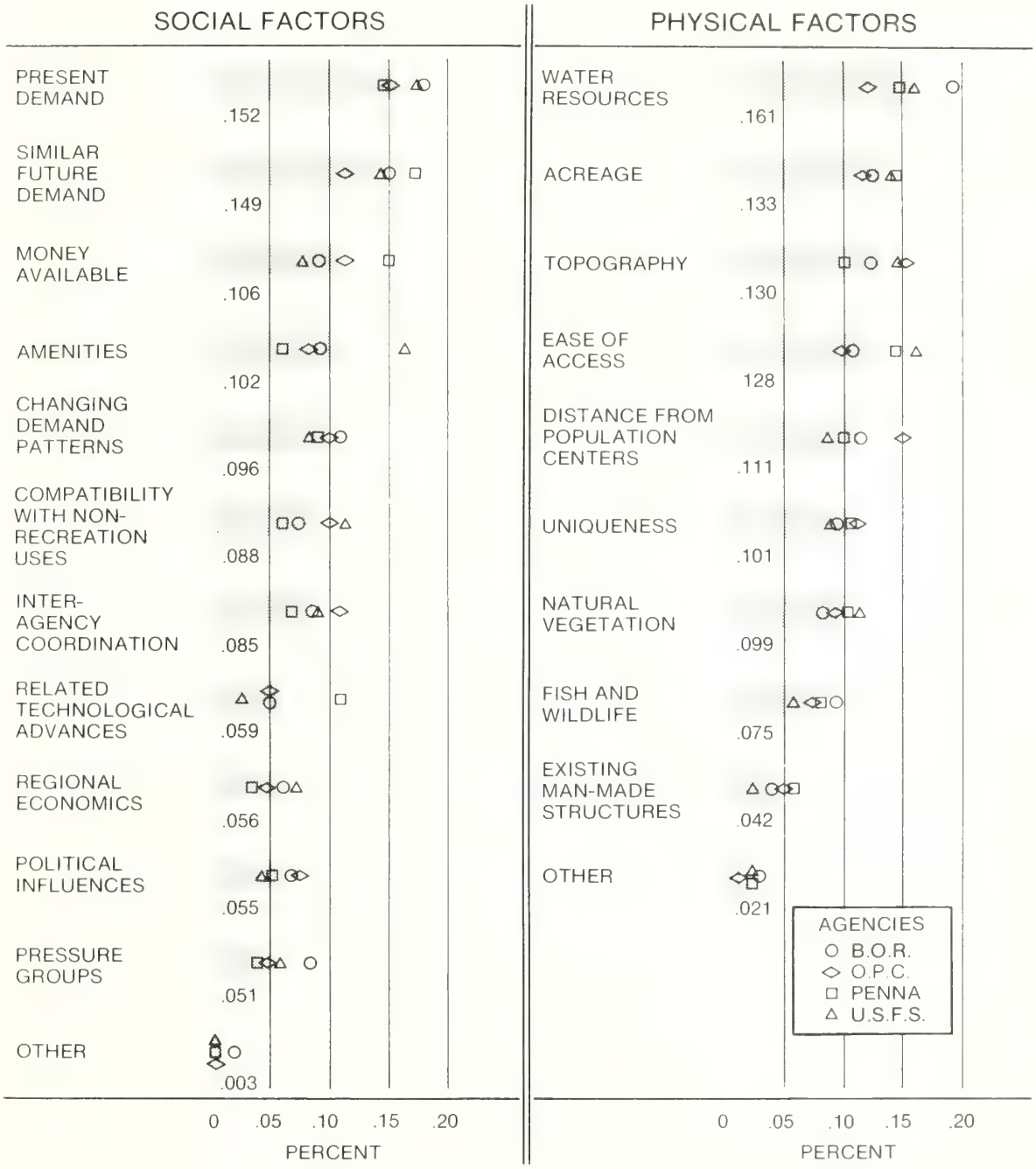
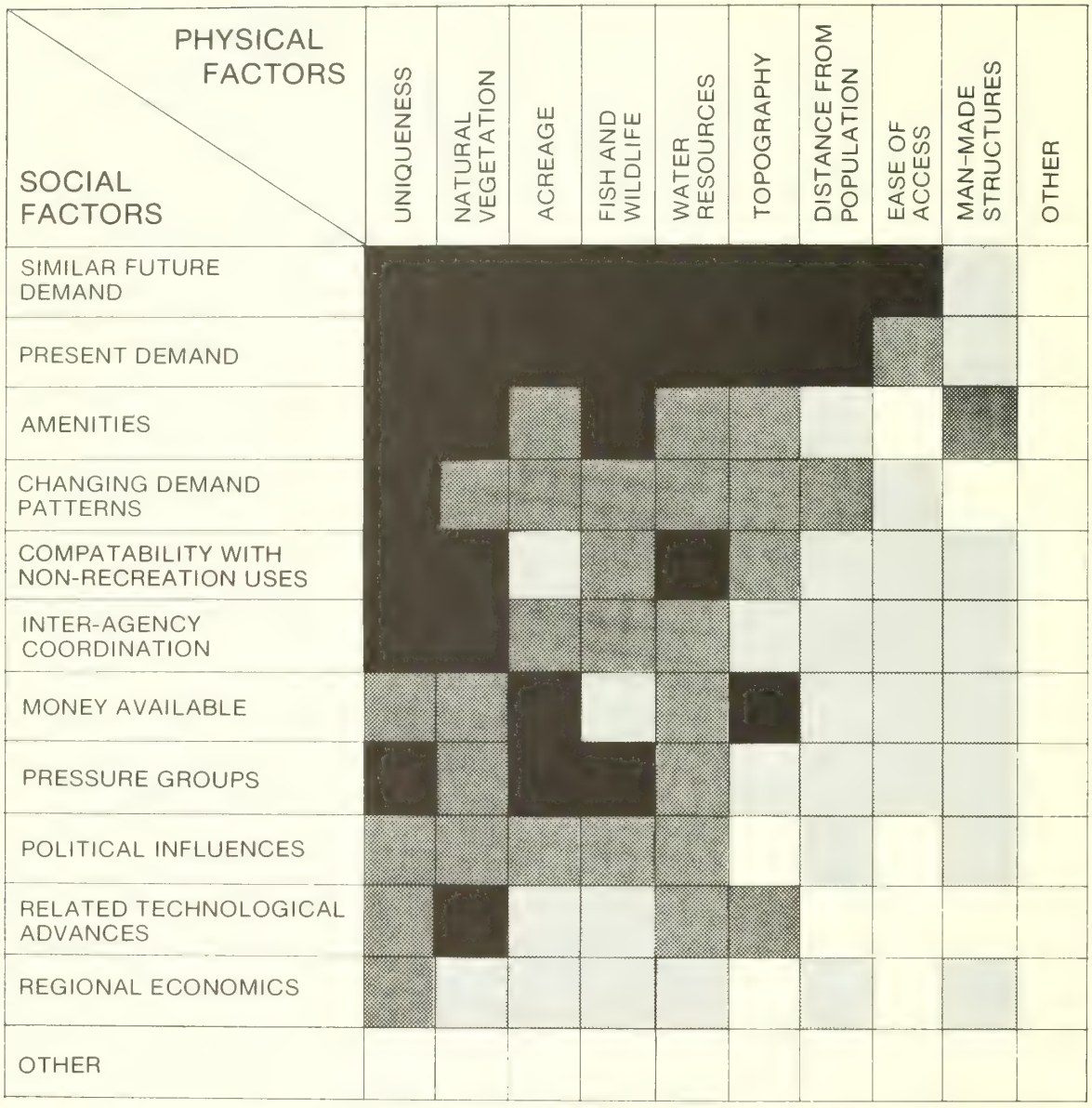
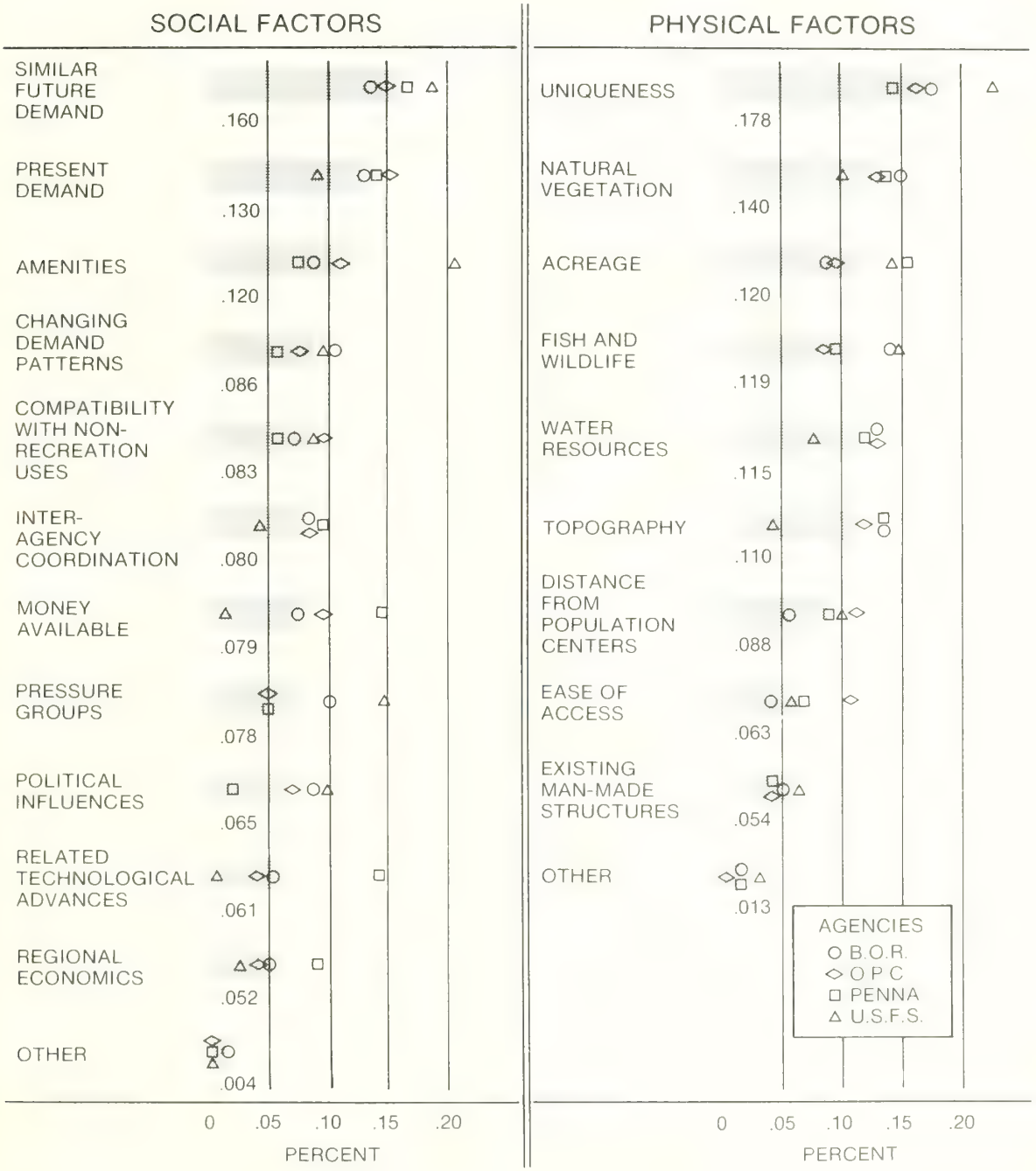


Figure 5.—Decision three: average relative importance given 120 social-physical factors in decision-making by four agencies.



QUARTILE:	UPPER	UPPER MIDDLE	LOWER MIDDLE	LOWER
SUM OF THE 30 PERCENTAGES WITHIN EACH QUARTILE	50	28	18	4
RANGE OF PERCENTAGES WITHIN EACH QUARTILE	.0309→.0112	.01116→.0077	.0074→.0042	.0040→.0001

Figure 6.—Decision three: social and physical decision factors arranged by average order of priority for all four agencies combined.



all agencies. This resulted in an average relevance tree for each of the three decisions.

To facilitate interpretation of the data, the percentage values in the average relevance trees were separated into upper, upper-middle, and lower quartile ranges. Each quartile range contained 30 social-physical factor combinations (fig. 1, 3, and 5).

In addition, the overall importance of any one factor in an average relevance tree was determined by adding percentage values across or down the rows or columns. Compiled this way, the sum of the percentages for either set of factors—social or physical—equaled 100 percent. This condition holds for any one interview (table 4, adjusted data) and also for the average relevance tree for any one decision.

The importance of individual social and physical factors varied considerably among the three decisions. However, percentage distributions showing the total influence of individual factors followed a similar pattern throughout all decisions (fig. 2, 4, and 6).

RESULTS

Decision-Maker Orientation

In decision one, 87 percent of the respondents chose to start with the social factors. In decision two, they were split about evenly. In decision three, 62 percent started with the physical factors.

From decision one through to three, there was a shift in orientation from social factors to physical-site characteristics. The effects of this shift were highlighted in the decision-maker's estimates of the social and physical factors that are important in influencing urban, rurals, and wildland recreation development decisions.

In the discussions that follow, if a social-physical factor combination value was in the upper quartile range of a relevance tree, we considered the combination as being very important or having high priority in the decision involved. If a social-physical combination value was in the upper-middle quartile range, we considered it as somewhat important; and if a combination was in the lower-middle or lower quartile range we felt it was not too important or of low priority in the decision involved (fig. 1, 3, and 5).

Of the 120 social-physical factor combinations considered in each decision, only about half had an important influence on any one of the three decisions. Regardless of the decision, the upper-quartile values always accounted for about half of the total influence in a decision; values in the upper-middle quartile always accounted for roughly another fourth of the influence.

Interagency Differences

For any one decision, priority values assigned to the various social and physical factors did not generally differ appreciably among agencies. Different public recreation-resource agencies assigned about the same values to most of the factors involved in the three decisions. This similarity among agencies implies that they may be expected to complement and coordinate their efforts and to understand the way each of them perceives the problems of recreation planning over a wide range of recreation resources and locations.

The only interagency differences discussed here involved factors that accounted for 10 percent or more of the total emphasis in a given decision.

In decision one, weights assigned by the individual agencies to *present demand*, *similar future demand*, and *uniqueness* of the area varied considerably from the average trend (fig. 2). These discrepancies among agencies may be caused by a certain degree of either major concern or unfamiliarity with the actual recreation development situation concerned.

In decision two, *amenities* were given a very high priority value only by the Forest Service (fig. 4). This agency is continually involved in decisions that weigh recreation uniqueness against productivity of an area for other forest products; and thus the constant need to consider amenity values may be reflected in this response.

In decision three, the Forest Service rated *amenities* and *uniqueness* factors somewhat higher than the average trend (fig. 6). These differences may be due partially to that agency's objective of providing wildland recreation

developments within the framework of the multiple-use doctrine.

Money available was rated both above and below average—depending on the agency involved. The variation may be due to existing budgetary constraints on a state agency as compared to federal agency.

The ratings assigned to social and physical factors for decisions two and three showed the least and greatest variability, respectively, between agencies (fig. 4 and 6). Overall, among the four agencies, social-factor ratings showed considerably more variation than physical factors.

Response patterns suggested that different recreation-resource agencies agree more often on the importance of physical factors, as compared to social factors, in management decisions. The importance of social factors is often influenced by the operating philosophies and goals of the agencies involved, while physical factors usually are fairly well defined in the minds of most decision-makers, regardless of their agency affiliation.

However, the few differences among agencies do not seem too serious most differences can logically be attributed to an agency's degree of involvement with a particular decision. At the same time, perhaps coordinated decision-making among various agencies to meet overall social goals may be hampered somewhat because of variation in priority values assigned to some social factors in the urban and wildland recreation decision situations (decisions one and three).

Recreation Demand

In the three decision situations, the respondents were concerned mostly with meeting present and similar future recreation demands for *today's* recreation activities. On the average, the social factors of *present demand* and *similar future demand*, in combination with most physical factors, always scored relatively high as important considerations—regardless of the decision.

On the average, for all agencies, *present demand* was slightly less important but still had top priority as respondents shifted from decision one to decision three. *Similar future demand* showed a slight upward trend from the urban to the wildland decision.

Changing recreation demand patterns were of secondary importance in all three decisions, and recreation-related *technological advances* had very low priority. Yet the interrelationship between technological advances and changing recreation demand patterns are only about one decade removed from most present demand situations (Esch, 1969). Nonetheless, decision-makers seem more interested in the problems of *current demand* than in potential *new demand* patterns that may emerge via new types of recreation equipment created by new advances in *technology*.

Some respondents said that they assumed that *future demand* was almost any type of recreation—including new types of activities not now in vogue. Thus there was a certain degree of overlap in respondent interpretation of the terms *changing demand patterns* and *similar future demand*. Therefore the decision-maker's concern about effects of technological advances may be more adequately expressed in his rating for *future demand patterns* than would seem to be the case in the graphed results (fig. 2, 4, and 6).

Present recreation-resource development decisions will likely perpetuate and increase demand for *today's* types of recreation activities—at least in urban and rural land environments. Decision-makers probably can make recreation demand whatever they want it to be, the major limiting factor being *money* for facility development—after consideration for the ecological integrity of an area.

If decision-makers continue to assign high priorities to *present* and *similar future demand*, one way to estimate future recreation demand 3 to 5 years from now would be to simply project demand on the basis of what recreationists do today or are likely to do in the very near future.

A useful way to estimate future recreation

demand might be to estimate how much money is available for recreation planning and development over the next 5 years and then convert this amount to expected demand based on today's recreation use/development cost ratios.

The drawback to such an approach for forecasting recreation demand 10 to 20 years from now is that priority values in future decisions may change. The present snowmobile boom is a classic example of this kind of phenomenon caused by new breakthroughs in technology and private advertising to promote the product.

Money

As might be expected, the amount of *money available* to achieve planning and development goals was a top-priority factor in decisions one and two, but was of secondary importance in decision three.

In decision one, the importance of money was associated with 8 of the 10 physical features of the resource (fig. 1).

In decision two, money was interrelated with six physical features as top-priority items (fig. 3); and in decision three, only five physical factors were assigned important monetary considerations (fig. 5). Regardless of the decision, *natural vegetation*, *acreage*, *water resources*, and *topography* were important physical-feature combinations always associated with *money* availability.

Amenities, Uniqueness, and Related Physical Factors

Recreation-resource executives do not overlook the importance of *amenity values* and the physical factors that contribute to those amenity values—such as *water resources*, *natural vegetation*, *fish and wildlife*, and *uniqueness* of the resource. Such factors are usually considered important in recreation-resource environments where they are already prominent, or where they will most likely occur. On the average, decision-priority ratings for recreation *amenity* and *uniqueness* factors increased steadily upward from decision one to decision three (fig. 1 to 6).

This upward shift becomes even more pronounced when one considers that the Forest Service (the agency concerned most with wildland recreation environments) assigned a very high priority rating to *amenity* and *uniqueness* factors in decision three.

A key element that affects the intrinsic or intangible values of any recreation environment is water. Existing or potential *water-resource* development opportunities were rated of medium importance in decision one, of maxium importance in decision two, and about as equally important as half of the other physical factors in decision three (fig. 2, 4, and 6).

The importance of *natural vegetation* and *fish and wildlife*, as they relate to *amenities* and *uniqueness* values, shifted noticeably from secondary importance in decisions one and two to top priority in decision three.

Overall, the respondents felt that *amenity* values and the physical factors that contribute to those values were two to three times more important in wildland recreation development than in urban recreation development.

Size of Area and Accessibility

Acreage of a potential recreation area has an important influence in the decision on how the area will be developed. The larger the area, the greater the opportunity for developing more kinds of recreation opportunities. The decision-maker's prime concern for the

size of a recreation area is related to his other major priority concerns—that is, trying to meet a variety of *present recreation demand* patterns and having enough space to provide a range of *amenity* values.

Ease of access and *distance from population* centers were major considerations in decision one (fig. 1 and 2). However, the importance of these two factors shifted steadily downward from decision one to decision three (fig. 5 and 6). This trend relates to present conditions: most wildland areas are farther from population centers and not as accessible as the recreation opportunities in decisions one and two.

Lower Priority Items

Throughout all three decisions, *interagency coordination* and *compatibility with non-recreation uses* were of intermediate importance.

The respondents placed *pressure groups* and *political influences* in low priority for all three decisions. They did not place much emphasis on the need for recreation developments to stimulate local or rural *economies*.

Any economic benefits generated by a recreation development may be somewhat automatic and thus may not be an important restrictive element in the recreation development decision process. *Existing man-made structures* in the area to be developed were also of low priority.

DISCUSSION

A decision cannot be fully and accurately evaluated by studying the quartile topography of a relevance tree. At best, the relevance trees used in this study are abstractions of some high and low points that affect three decisions.

Inferences are limited to what can be seen in two dimensions. Through a clearer understanding of priorities in these decisions, executives may systematically wish to change priorities of social and physical factors to increase the overall direction of a given decision. In a sense, the relevance trees are simulated chessboards, and we have tried to identify those squares where the powerful pieces are most likely to be.

The relevance trees used in this study also provide a reference point for measuring future changes in the perception of important factors in the decision-making process. A relevance-tree study in the future would point out—in comparison with results from the current study—where important changes in decision behavior patterns occurred. Such changes may be caused by future re-orientation of management procedures, changes in policy, or unexpected changes in recreation demand patterns.

The PATTERN methodology permits executives in one agency to better understand what their counterparts in other agencies feel are the important constraints in the decision-making process. Such information permits the various agencies to better coordinate their efforts to provide a wide range of recreation opportunities.

Furthermore, relevance-tree values developed in this study can help to delineate subject-matter areas and priorities for further research efforts. In-depth research that deals with factors at various high points (upper quartile) of relevance trees seems more justifiable than research studies in the lower-middle and lower quartiles. In this regard, any research aimed at forecasting demand or use of recreation facilities and research on management procedures for optimum allocation of operating budgets would be extremely helpful to recreation managers.

Priority values computed in this study can also be useful in developing resource-management decision games that can help decision-makers evaluate the consequences of various decision alternatives.

In general, the decision-makers who took part in our study assigned highest priorities to those factors that related to the immediate consequences of their decisions. *Present demand, money available, similar future demand*—in combination with most physical aspects of the resource—are the key considerations in decisions about outdoor recreation developments in urban, rural, and wildland areas.

REFERENCE

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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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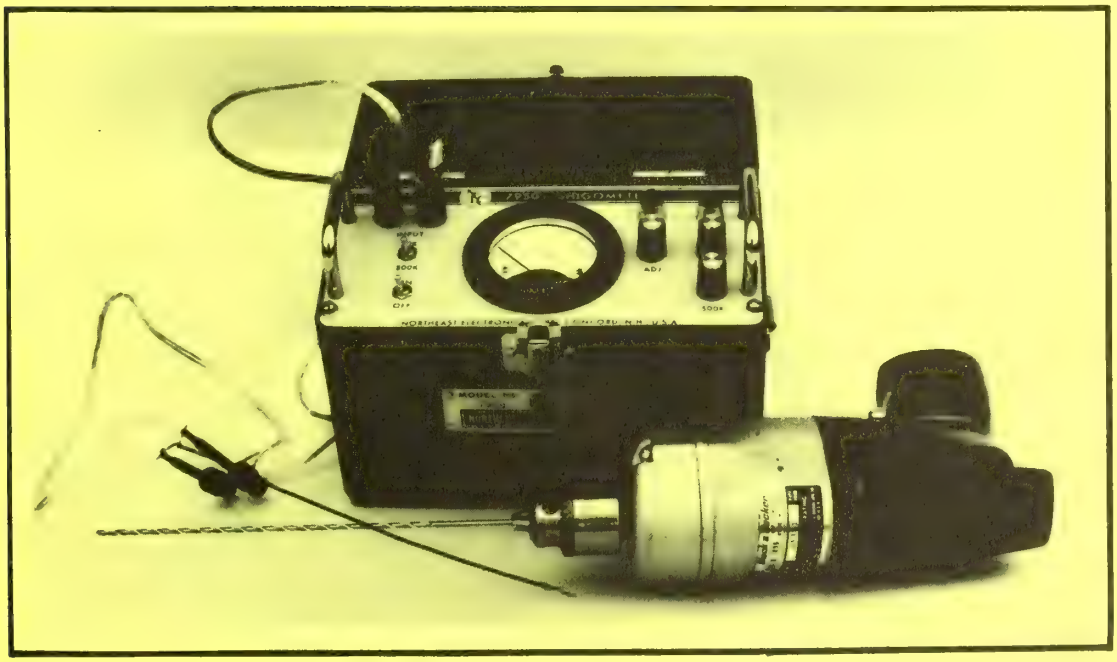
DETECTION OF DISCOLORATION AND DECAY IN LIVING TREES AND UTILITY POLES

by Alex L. Shigo
and Alex Shigo



USDA FOREST SERVICE RESEARCH PAPER NE-294
1974
NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082
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MANUSCRIPT RECEIVED FOR PUBLICATION 12 MARCH 1974

Abstract

A method is described for detecting discoloration and decay in living trees and creosoted utility poles. The method and devices have come from research involving many people over a seven-year period. A probe was inserted into a 3/32-inch (2.4 mm) diameter hole made by drill bits 8 inches (20.32 cm) and 12 inches (30.48 cm) long mounted in a portable, light-weight, battery-operated drill. The probe was attached by a flexible cable to a portable, light-weight, battery-operated meter, a "Shigometer", that delivered a pulsed electric current and measured resistance to it. As the probe was inserted into the hole, the meter measured in ohms the resistance of the wood in contact with the probe tip. As the probe was pushed inward, if the tip contacted only sound tissues, slight changes in resistance were measured. When the probe tip passed from sound wood to discolored or decayed wood there was an abrupt decrease in resistance. The magnitude of the decrease in resistance indicated the degree of discoloration or decay. The depth of the probe when the needle on the meter began to decrease indicated the position of the discolored or decayed wood.

DISCOLORATION and decay are major causes of damage to living trees, utility poles, and wood products throughout the world. Too often the defects are not detected until it is too late: a tree falls on a house, car, power line, or person; a bridge collapses; a tree that appeared valuable for timber turns out to be valueless because of discolored and decayed wood on the inside; or a utility pole falls during a storm or while being climbed. The wood has been weakened by decay.

Discoloration and decay of wood are caused by bacteria and fungi that digest wood inside of trees and poles, hidden from view. In a living tree, wounds start the processes; microorganisms often invade the exposed wood and discoloration and decay may follow when conditions are proper (for details on discoloration and decay processes see *Shigo and Larson 1969*). In utility poles, decay microorganisms are sometimes active in the poles before they are put in service, or microorganisms may invade at any time later when conditions are proper (for details on decay process in poles see *Eslyn 1970*). In North America, nine species of fungi cause most of the decay in utility poles (*Eslyn 1970*).

In living trees wounds should be prevented. When wounds are inflicted they should be treated properly (*Shigo and Wilson 1971*). Poles should be treated properly with preservatives to prevent decay. But many times even when proper measures are taken for prevention, some microorganisms still invade and discoloration and decay develop. Then early detection of discoloration and decay become all-important. The earlier discoloration and decay are detected, the earlier a decision on action can be made: remove the tree or pole, lower the timber value of the tree, increase tree vigor by pruning, fertilizing, watering, etc.

The need for a method of detecting decay in trees and utility poles has been long recognized and research has been done with X-ray units (*Eslyn 1959*), ultrasonics (*Miller et al. 1966*), and a needle that measures resistance to pressure (*Zycha and Dimitri 1962*, *Eslyn 1968*). Eslyn (*1968*) reviews other methods for detecting decay in utility poles. The methods and equipment now available have not been accepted widely and put into practice, especially in living trees. The equipment is either too expensive, not easily portable, or not accurate, or the methods require a high degree of training. And, at best, they detect advanced decay and not incipient decay and discoloration.

A new method of detecting discolored and decayed wood in living trees was described by Skutt et al. (*1972*). The basic information for the method came from research on the electrical properties of wood (*Lin 1965*, *1967*) and the pioneering work on electrical properties of trees by Fensom (*1957*, *1960*, *1963*, *1965*). The new method is based on two principles: resistance to a pulsed current decreases as concentrations of cations increase in wood; and as wood discolors and decays the cations potassium, calcium, manganese, and magnesium, increase (*Shigo and Sharon 1970*, *Tattar et al. 1972*, *Shortle and Shigo 1973*, *Safford et al. 1974*). As wood decays, cations increase and resistance decreases. Skutt et al. (*1972*) and Tattar et al. (*1972*) showed that the method detected discolored wood and de-

cayed wood in living trees when the wood was above the fiber-saturation point (approximately 30 percent w/w). The method not only detected discolored and decayed wood but indicated the degree of tissue deterioration.

Skutt et al. (*1972*) reported these results from experiments that used a meter first constructed by Ronald M. Lessard.[1] The measurements were made with steel nails insulated except for their tips. As two nails were driven parallel at 2 cm apart into a tree, the resistance to a pulsed current of the wood between the nail tips was measured. Measurements were also made on freshly cut wood sections with the nails and with needle probes of the type used for making moisture readings in wood.[2]

Although the reports on the method showed that discolored wood and decayed wood could be detected accurately in living trees, two important weaknesses kept it from being accepted for wide use in the field: only expensive, fragile laboratory models of the meter were available, and the nail probes and other probing methods were not practical.

This paper reports a method of detecting discolored and decayed wood in living trees and creosoted utility poles that uses a relatively inexpensive, durable meter with a printed circuit, manufactured by Northeast Electronics Corporation, Concord, New Hampshire,[3] and an inexpensive, single probe developed by the second author.[4,5] The method and devices have been developed through the efforts of many people over a 7-year period.

[1] Mr. Ronald M. Lessard was a graduate research assistant in the Department of Electrical Engineering, University of New Hampshire and a part time employee of Dr. Alex L. Shigo of the Northeastern Forest Experiment Station, U.S. Forest Service, Durham, New Hampshire when the first meter was developed, and the method first tried.

[2] Probe handle and pins manufactured by Delmhorst Instrument Company, 607 Cedar Street, Boonton, New Jersey 07005.

[3] The use of trade, firm, or corporation names in this paper does not constitute endorsement by the Forest Service or the U.S. Department of Agriculture.

[4] Patent on probe pending by Northeast Electronics Corporation, Airport Road, Concord, New Hampshire.

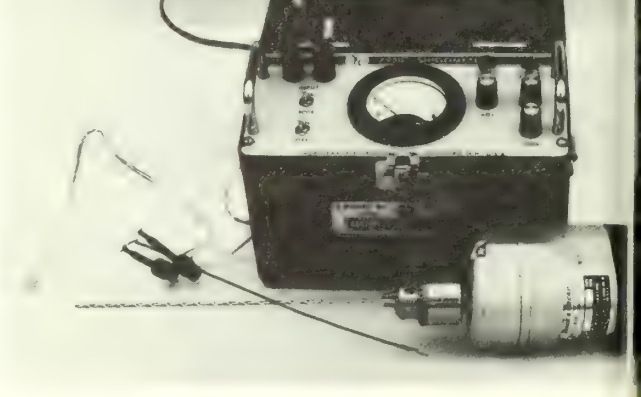
[5] The commercial model of the meter is called a Shigometer Model 7950 by Northeast Electronics Corporation.

MATERIALS AND METHODS

The Shigometer

The meter manufactured by Northeast Electronics Corporation has a circuit similar to that described by Skutt et al. (*1972*). The meter is small and light in weight (fig. 1). The printed circuit makes it reliable and durable for field use. It is powered by six 1.4 volt batteries. (Newer models will use 1.5 volt batteries also). It has scales of 50 and 500 K ohms. Both scales and zero can be adjusted by front panel knobs.[6]

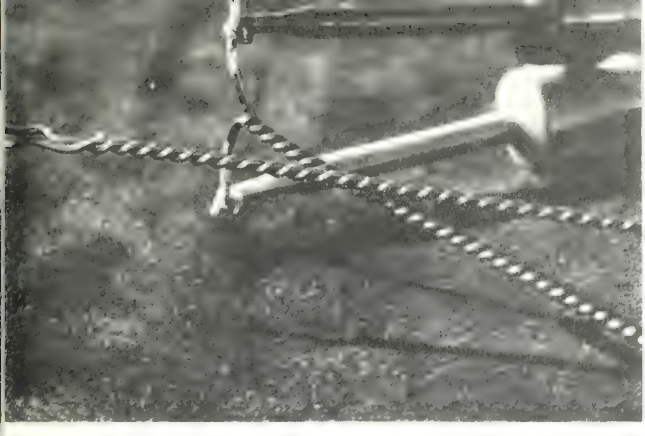
Figure 1.—Pulse resistance meter, "Shigometer," tw wire probe, and drill for detection of discolored decayed wood in trees and utility poles.



The Probe

The probe was made of two enamel-insulated copper wires, the type used on electric motor armatures. The two wires were twisted together by placing two ends in a vise and the opposite ends in the chuck of a twist drill. Probes of two diameters were made; one from gauge 19 wires and the other from gauge 20 wires. A bell-shaped curve was formed with pliers in each wire at the probe tip (fig. 2).

[6] Additional details on the Shigometer Model 7950 can be obtained from the Instruction Manual published by Northeast Electronics Corporation, Concord, New Hampshire.



ıre 2.—Twisted wire probe for detecting discolored decayed wood. Solder coats the exposed portions of bell-shaped curves to increase sensitivity. Opposite of probe is attached to flexible cable.

The curves were offset slightly at the tips, as one wire was longer than the other. The enamel coating was removed from the tops of the bell-shaped curves and this exposed portion of the wire was coated with solder. On the opposite end of the probe the two wires were spread at right angles. The enamel coating was removed from these ends to 1 cm and these exposed portions of the wires were coated with solder. Probes 20 and 30 cm long were made. Probes made from 19 gauge wire were 1.7 mm in diameter and had approximately 5 twists per cm. Probes made from 20 gauge wire were 1.3 mm in diameter and had approximately 6 twists per cm (fig. 2).

The Method

The meter is turned on and adjusted for the zero, 50, and 500 K ohm scales (K=thousand). The probe is attached to the meter with a long flexible cable (fig. 1). A hole is drilled and the probe is inserted slowly into it. The exposed portions of the wires at the top of the bell-shaped curves at the probe tip press against the walls of the hole. The pulsed current from the meter passes through one wire and into the wood at the exposed top of the curve. The current passes through the wood and returns to the meter through the exposed top of the curve on the other wire. The resistance to a pulsed current of the wood between the exposed tips of the probe is indicated in K ohms on the meter. The probe is pushed slowly into the hole and the needle of the meter watched. When abrupt changes in resistance occur, the probe is pulled out of the hole slightly, and then pushed in again to verify the change and its depth. The probe is pushed in again very slowly to determine the exact depth of the tip when the needle on the meter begins to drop. This indicates the position of the defect. Before the probe is used again the tips are spread apart to restore tension. Care is taken to keep the probe tip clean, especially when used in conifers that ooze sap and in freshly creosoted utility poles. A clean probe tip registers beyond 500 K ohms in open air and in deionized water.

Living Trees

One hundred white pine, *Pinus strobus* L. logs were measured a few days after they were cut. Several holes were drilled to depths of 8 inches (20.32 cm) and 12 inches (30.48 cm) 5 cm from the cut ends. The resistance measurements were compared with the wood at the exposed cut end. The same procedure was done for 13 red oak, *Quercus rubra* L., 9 eastern hemlock, *Tsuga canadensis* (L) Carr., 12 red maple, *Acer rubrum* L., 4 yellow birch, *Betula*

Figure 3.—The long drill bit should be supported between fingers until it is deep into the wood. The turning drill bit will not harm fingers.

alleghaniensis Britt., and 8 black walnut, *Juglans nigra* L. In preliminary studies many species of trees were measured: sugar maple, *A. saccharum* Marsh., paper birch, *B. papyrifera* Marsh., sweet birch, *B. lenta* L., American ash, *Fraxinus americana* L., aspen, *Populus tremuloides* Michx., beech, *Fagus grandifolia* Ehrh., elm, *Ulmus americana* L., balsam fir, *Abies balsamea* (L.) Mill., and white Oak, *Q. alba* L.

Utility Poles

Fifty poles were measured in the field at the groundline and 1 ft (30.48 cm) aboveground. Increment cores were extracted 1 cm from the drill holes and taken to the laboratory for examination and comparison with the meter measurements. Nine additional poles were pulled from the ground and the lower 6 ft (1.83 m) sections were taken immediately to the laboratory. Eight holes to a depth of 8 inches (20.32 cm) were made at groundline, 1 ft (30.48 cm) aboveground, and 1 ft (30.4 cm) belowground. Additional holes were made between these points and below the 1 ft (30.48 cm) belowground position. At least 30 holes per section were made, and the resistance at 1 cm intervals inward was recorded. The sections were dissected to determine the actual condition of the wood at the position of each measurement.

Condition of Wood Surrounding Drill Holes

From May to September 1972, hundreds of holes 3/32 inch (2.4 mm) in diam to 6 inches (15.24 cm) deep were made in 10 each white pine, red oak, paper birch, and red maple on the Massabesic Experimental Forest near Alfred, Maine. The objective of the study was to determine the changes in resistance measurements in the same trees over a 5-month period. Most trees received over 50 holes during this period. Many holes were clustered together while others were separated. The holes were in the trunks of trees ranging in diameter from 10 to 20 cm at 1.4 m aboveground. The holes were concentrated in the trunk from 0.5 to 2 m aboveground. In December 1973, 4 white pine, 3 paper birch, 4 red maple, and 2 red oaks were cut and dissected to determine the condition of the wood surrounding the holes.

Other Probes and Probing Techniques

On living trees and utility poles a wide variety of other probes and probing techniques were tested: steel nails 85 x 3 mm insulated except for their tips, single rods of stainless steel 200 x 2 mm coated with alternating layers of conducting and non-conducting materials, drill bits of varying lengths and diameters insulated except for their tips, and double needle probes of the type used with moisture meters.

On 95 standing utility poles the probes were tested alone and in combination with others: the nails were placed at different positions around the pole and driven to varying depths; a nail was used as a reference probe at one depth and a drill bit insulated except for its tip was driven inward at one position; the single steel rod with alternating coats of conducting and non-conducting materials was pushed slowly into the holes; the double needles were pushed into the poles at varying positions and depths. Similar tests were done on 70 logs from 26 hemlock, *T. canadensis*, as part of a study by the State of Vermont on more effective use of hemlock.

The objectives of our part of the study was to determine whether any meter reading or combination of meter readings could be related to the quality of boards sawn from the logs. The needle probes were used on over 100 balsam fir, *Abies balsamea* and red spruce, *Picea rubra* L. to determine whether the resistance measurement at the cambial area were related to the degree of decline due to defoliation by the spruce budworm. A similar study was done on white pine to determine whether some relationship existed between resistance measurements and vigor. Over 25 mature trees, obviously vigorous and obviously declining, were measured. Details on these preliminary studies and others on the method can be obtained from the first author. Mention of these and other studies is made only to indicate that a wide variety of tests have been conducted with the meter.

RESULTS

The twisted wire probe and Shigometer detected discolored and decayed wood in living trees and utility poles. Discolored and decayed wood was detected not on the basis of absolute resistance measurements but on the pattern of resistance measurements (tables 1, 2, 3, and 4). In sound wood in trees and poles there were only slight changes in the resistance measurements as the probe was pushed inward. In some trees and poles the measurements were beyond 500 K ohms the entire length of the hole. In poles this occurred usually where the wood was dry and sound or freshly saturated with creosote. As the probe was pushed inward through obviously sound tissues, discolored and decayed wood was detected by an abrupt decrease in the resistance. The magnitude of the decrease indicated the degree of tissue deterioration. For example, a decrease from 400 to 20 K ohms indicated advanced tissue deterioration. An abrupt decrease was verified by pulling the probe out slightly beyond the suspected area and pushing it in again slowly through the suspected area. The depth of the exposed top of the bell-shaped curve farthest from the probe tip at the moment the needle began to drop marked the exact position of the interface between sound and discolored or decayed wood. This sharp boundary was most pronounced in living trees where there was an abrupt margin between sound and unsound wood.

In poles the change from sound to unsound tissues was usually more gradual. To determine the exact depth of any tissue change, the probe was extracted at the point where the change occurred and the length to the farther bell-shaped curve was measured. Or, the portion of the probe out of the hole was measured and subtracted from the total length of the probe to the farther bell-shaped curve.

In white pine, red oak, and black walnut that have a heartwood core, the resistance measurements were low in the inner bark (5 to 15 K ohms) slightly higher in the sapwood (20 to 50 K ohms) and higher still in the heartwood (60 to 300 K ohms). Wardell and Hart (*1973*) reported that P, K, Mn, Mg, and Ca decreased as sapwood died and heartwood formed in white oak, *Quercus alba*. The decrease in these cations would result in an increase in resistance to a pulsed current. In some trees the sapwood-heartwood boundary was detected accurately as resistance increased abruptly. In other trees, the gradation of tissue changes from sapwood to heartwood was gradual. Here the probe did measure an increase in resistance but it was not abrupt. In sound heartwood, the resistance measurements decreased only slightly as the probe moved inward through older tissues. Low resistance readings were common near the pith. In many trees discolored heartwood was present. In white pine, the resistance of sound, clear heartwood was usually above 300 K ohms, that of discolored heartwood was from 250 to 200 K ohms, and the resistance of decay was below 200 K ohms. Discolored heartwood in white pine was difficult to detect visually. Although these results are based on 100 trees, it must be emphasized strongly that *the pattern* and not the absolute reading is important in determining the internal condition of a tree, and the resistance measurements given here are examples only.

In red oak and black walnut a similar pattern of changes occurred. The resistance measurements for oak were higher than those for walnut. Discolored and decayed wood in oak and walnut often had resistances below 50 K ohms. Wetwood or advanced discolored heartwood was detected in these trees.

In red maple and yellow birch, which have no heartwood core, the abrupt changes in measurements were the most dramatic. The boundaries between discolored wood, decayed wood, and sound wood were detected accurately.

In hemlock the colored central core, which is commonly called heartwood, had resistance measurements lower than sapwood. This discolored core could be discolored wood that formed as a result of branch stubs, or heartwood that was discolored throughout. More dissections and measurements are needed before the true nature of this discolored core can be resolved. The hemlock had many abrupt increases and decreases in resistance as the probe was pushed inward, indicating that alternating columns of discolored wood, decayed wood, and sound wood were common in these

Table 1.—Examples of resistance patterns in red maple

Sound Sapwood, bark to 8 inches inward							
1	2	3	4	5	6	7	8
300	250	220	310	280	260	340	290
500	450	500	500	475	475	500	500
400	320	375	450	400	350	200	210
275	300	260	240	200	205	200	200

Sound Sapwood to 5 inches				Discolored wood 5 to 8 inches			
1	2	3	4	5	6	7	8
300	250	320	310	40	45	35	30
500	450	500	500	80	65	75	50
400	320	375	450	30	40	35	25
275	300	260	240	25	20	18	15

Sound Sapwood to 4 inches		Discolored wood 4 to 6 inches				Decayed wood 7 to 8 inches	
1	2	3	4	5	6	7	8
300	250	320	40	45	35	5	2
500	450	500	80	65	75	3	1
400	320	375	30	40	35	2	2
275	300	260	25	20	18	8	6

Sound Sapwood to 3 inches		Discolored wood 3-5 inches		Decayed wood 5-7 inches		Hollow center 7-8 inches	
1	2	3	4	5	6	7	8
300	250	40	45	5	2	>500	>500
500	450	80	65	3	1	>500	>500
400	320	30	40	2	2	>500	>500
275	300	25	20	8	6	>500	>500

Table 2.—Examples of resistance patterns in red oak

Sound Sapwood to 2 inches		Sound Heartwood 2-4 inches		Discolored Heartwood 4-6 inches		Decayed Heartwood 6-8 inches	
1	2	3	4	5	6	7	8
50	70	130	200	80	60	20	25
70	80	200	320	120	130	15	10
100	90	290	250	60	40	5	3
120	150	400	450	150	125	30	35

Sound Sapwood to 2 inches		Sound Heartwood 2-4 inches		Discolored Heartwood 4-5 inches	Decayed Heartwood 5-6 inches	Hollow Center 6-8 inches	
1	2	3	4	5	6	7	8
50	70	130	200	80	7	>500	>500
70	80	200	320	120	15	>500	>500
100	90	290	250	60	5	>500	>500
120	150	400	450	150	35	>500	>500

Table 3.—Examples of resistance patterns in white pine

Sound sapwood to 2 inches		Sound Heartwood 2 to 8 inches					
1	2	3	4	5	6	7	8
150	200	350	380	340	400	425	325
200	250	300	325	250	320	350	275
300	350	450	475	500	500	400	375
400	425	500	500	>500	>500	>500	400

Sound sapwood to 2 inches		Sound Heartwood 2 to 6 inches		Discolored Heartwood 6 to 8 inches			
1	2	3	4	5	6	7	8
150	200	350	380	340	275	250	225
200	250	300	325	250	200	175	200
300	350	450	475	500	400	375	350
400	425	500	500	>500	450	350	375

Sound sapwood to 2 inches		Sound Heart-Wood 2-4 inches		Discolored Heartwood 4-6 inches		Decayed Heartwood 6 to 8 inches	
1	2	3	4	5	6	7	8
150	200	350	380	275	250	225	200
200	250	300	325	200	175	150	150
300	350	450	475	400	375	200	230
400	425	500	500	450	350	220	210

Table 4.—Examples of resistance patterns in utility poles

Sound wood 1 to 8 inches							
1	2	3	4	5	6	7	8
400	450	425	400	410	450	425	430
300	325	300	330	350	320	360	300
450	400	425	475	500	>500	400	450
500	>500	>500	>500	>500	>500	>500	>500

Sound wood to 4 inches				Decay from 4 to 8 inches			
1	2	3	4	5	6	7	8
400	450	425	400	200	150	100	50
300	325	300	330	200	175	100	125
450	400	425	475	150	125	50	175
500	>500	>500	>500	400	450	275	300

trees. Results of the studies on hemlock suggested that resistance measurements of the tissues midway through the pith and the sapwood-discolored wood boundary were most related to the grades of boards sawn from the logs. When low resistance was measured in these tissues, more low quality than high quality boards came from the log (detailed results of this study can be obtained from the first author).

In all trees that had hollows, they were detected. The tissues surrounding the hollow were discolored or decayed, and very low measurements resulted. When the probe tip penetrated the hole, the needle on the meter swung from low readings on the left abruptly to the right, off scale, indicating infinite resistance; probe in air. When the tip of the probe touched the opposite side of the hollow, the needle swung abruptly back to the left; on scale. The diameter of the hollow was determined from the depths of the probe when the needle swung off scale to the right and then back to the left on scale.

In some trees the drill hole penetrated columns of advanced wetwood. (Wetwood is wood that has high moisture, pH, and concentrations of cations, and gas resulting from invasion of microorganisms, especially certain species of bacteria). Water and sometimes gas flowed from the holes. The water flowing out the hole soaked the walls with cations, and only low readings were recorded the entire length of the hole. Wetwood was common in paper birch, yellow birch, red maple, and black walnut.

Utility Poles

Of the nine poles that were pulled and dissected, all had some decay; four had decay 1 ft (30.48 cm) belowground, five had decay at groundline, and five had decay 1 ft (30.48 cm) aboveground. The meter detected decay accurately in all poles. At 1 ft (30.48 cm) aboveground the resistance was over 500 K ohms in sound, dry, or creosoted wood. When the probe tip touched incipient decay, the needle on the meter swung from the right abruptly to the left, on scale. The abrupt needle movement from off scale on the right to on scale on the left was indicative of an early stage of decay. The magnitude of the decrease in resistance indicated the degree of tissue deterioration. At the groundline when some moisture was in sound wood, the resistance was lower than in dry poles, but there was no abrupt drop in resistance as the probe was pushed the entire depth of the hole. And again, any abrupt decrease indicated decay. The same pattern occurred at 1 ft (30.48 cm) belowground.

In some poles the central core of heartwood had not been penetrated by creosote. This is common. In sound heartwood cores, whether penetrated by creosote or not, there was a slight increase in resistance over the creosoted sapwood; but in decay in the heartwood cores, the resistance decreased.

In the 50 poles measured in the field at 1 ft (30.48 cm) aboveground and at groundline, the same pattern of measurements occurred as in the dissected poles. At groundline, 19 poles were sound and had resistance readings beyond 500 K ohms, the entire depth, 11 had some decay with readings between 0 and 200 K ohms, and 10 had small pockets of incipient decay. At 1 ft (30.48 cm) aboveground 20 poles had resistance measurements beyond 500 K ohms, 4 had some decay with resistance below 500 K ohms, and 16 were generally sound with very small areas of unsound wood. The presence and position of decay in the poles was confirmed by close examination in the laboratory of the large increment cores. The meter was accurate in detecting decay in all poles.

Decay was most advanced at the groundline to 1 ft (30.48 cm) belowground in the nine poles that were pulled and dissected. Poles with decay at the groundline were sound at the bottom and 2 ft (60.96 cm) aboveground.

Measurements on trees and poles were continued until February, 1974. The meter was kept outside in temperatures near 0°F (−18°C) for 8-hour periods during the tests. The meter performed perfectly under winter conditions and decay was detected except when the wood was frozen. But in most cases with living trees the wood was seldom frozen more than 5 cm in and decay was still detected when it occurred deeper in the trunk.

Results of Drilling Holes in Trees

Discolored wood was associated with all drill holes after 1 and 2 years, although all but a few were healed. The discolored column associated with the hole was approximately the diameter of the hole and extended from 1 to 20 cm above and below the hole. The discolored columns were most advanced where many holes were clustered. The wood that formed after the hole was made was not discolored. The discolored columns were most advanced in paper birch and red maple. Very small columns—1 to 5 cm in length—were in oak. The slight discoloration in the heartwood was difficult to see after the wood dried. In white pine it was difficult to see the faint outline of the discolored column, even immediately after it was dissected.

Drill Procedures

A 30 cm deep hole was drilled in a pine in 15 sec. In birch and maple a 20 cm deep hole was drilled in less than 30 sec., and in oak, 30

to 50 sec. In poles a 20 cm deep hole was drilled in 10 to 20 sec. From drilling to measurements took less than 3 min in poles and trees.

In many cases the drilling procedure alone detected advanced decay, wetwood, or a hollow. A sudden release on the torque pressure indicated decay or a hollow. And the dark drill bit shavings also indicated that discolored or decayed wood was present.

Other Probes and Probing Techniques

The nails that were insulated except for their tips did detect discolored wood and decayed wood in trees as reported by Skutt et al. (*1972*) and Tattar et al. (*1972*) when the tips touched the defect. They detected decay in poles also. But it was very difficult to pound them in and extract them. The nails used in various patterns around poles and trees did not accurately detect internal decay unless the tips of the nails touched the decay.

The single steel probe with the alternating coats of conducting and non-conducting material gave inconsistent results. When the probe tip made close contact with the walls of the hole, decay was detected. The coatings were very fragile and slight cracks in the coatings made the probes useless. The probe often would not penetrate the hole because the holes were slightly curved and the probes were straight. The close layers of conducting and non-conducting materials caused the probes to give false readings due to capacitance effects. The drill bits that were insulated except for their tips detected decay, but it was difficult to operate two drills at the same time. The technique was cumbersome.

Combinations of probes and other probing techniques were not consistently accurate. The nail-reference probe used with a drill insulated except for the tip was not accurate.

The double needle moisture probe was accurate in detecting discolored and decayed wood on the freshly cut ends of logs. The probe detected discolored heartwood and slightly colored wetwood in sapwood. As a research tool, the needle probes indicated the gradation of tissue deterioration from advanced decay to the early stages of discoloration.

The results of studies on white pine, balsam fir, and red spruce suggest that there is a relationship between low resistance (5 to 10 K ohms) and high vigor, and higher resistance (11 to 30 K ohms) and low vigor or advanced degree of decline.

DISCUSSION

Discolored and decayed wood was detected in trees and utility poles by the pattern of changes in resistance to a pulsed current. An abrupt decrease in resistance indicated the presence of discolored or decayed wood. The Shigometer with the twisted wire probe has the potential for practical use in the field. Compared to X-ray units and ultrasonics, the equipment for the resistance method is very inexpensive, safe, and requires very little training. The equipment is light in weight, easily portable, and very durable under winter and summer field conditions. And, when it is used properly, the measurements are accurate.

Some discolored wood was associated with the holes made by the drill bits after two growing seasons even though most of the holes healed. The discolored wood associated with holes in white pine and red oak was very slight. The number of holes—often over 50 in one area of the trunk—would never be drilled in one tree under normal field testing. Where the tree was to be cut in a few months, little or no discoloration would be associated with the hole. When conifers or deciduous hardwoods that have a heartwood are to be drilled, very little discolored wood would result. The minute column of discolored wood would not harm an ornamental tree. Discolored and decayed wood is compartmentalized in living trees. The tissues that form after a wound are not infected unless other wounds are inflicted (*Shigo and Hillis 1973*).

The question may be asked concerning the value of the twisted wire probe when a hole must be made first. Why not just extract an increment core? The hole made by an increment borer is many times larger in diameter—8

to 12 mm—than that made by the drill bit—2 to 3 mm. The columns of discolored wood, and sometimes decay of wood associated with such large increment borer holes are many times larger than those associated with the holes made by the minute drill bits (*Lorenz 1944, Hepting et al. 1949*). Houston (*1971*) showed that increment borer holes treated with some chemicals, especially those that restricted oxygen, retarded the development of discoloration in red maple and yellow birch. If the slight amount of discolored wood was considered a problem in the small drilled holes, the holes could be treated with chemicals to minimize the development of discoloration. The same could be said for poles, where creosote could be applied to the drill hole.

The increment core presents some more serious problems. The major one is that the core must be examined carefully by an expert before incipient decay or discolored wood, especially discolored heartwood, could be detected with certainty. Often, the core must be taken to a laboratory for such an examination. The normal change of color of heartwood not penetrated by creosote in utility poles would be very difficult to differentiate from the color of incipient decay. With the twisted wire probe, the slightest changes in the tissues are detected.

The probe and meter indicated the position of discolored and decayed wood, and it indicated how advanced the deterioration was. From this information the hazard risk of poles and ornamental trees, and the timber value of forest trees could be determined.

There are still some situations where the probe will not detect discolored or decayed wood. When the drill hole is flooded by water from a wetwood zone is an example. Still the boring at such a zone and the rush of water and gas from the hole indicates an advanced wetwood zone. The question then is: do you need the probe where the condition of the wood surrounding the hole is obvious? Another situation where the probe does not function properly is in dry decay such as that associated with some wounds on conifers. But, preliminary results (*Joe Clark, Forest Products Laboratory, U.S. Forest Service, Personal Communication*) suggest that dry areas in wood products can be rewetted with deionized water and then the probe will detect decay. Also preliminary results (*James Ward, Forest Products Laboratory, U.S. Forest Service, Personal Communication*) suggest that the probe can be used to sort timbers for kiln drying. Boards with bacterial wetwood gave low readings. Such boards often require special kiln schedules. And because moisture and concentrations of cations in the cambial area of living trees are altered as they wane, the meter may be helpful as an indicator of tree vigor, or the degree of decline.

Zhuravleva (*1973*) showed that the resistance of cambial tissues in *Picea abies* was inversely correlated with annual radical increment. Vigorous trees had low resistances while low vigor trees had high resistances. The method can also help as a research tool to quantify changes in wood tissues after wounding and invasion by microorganisms. At moisture contents below the fiber-saturation point the meter acts as a regular moisture meter. An expanded scale to 3000 K ohms with other minor changes in the electrical circuit would convert the present meter to a moisture meter that could measure moisture to 5 percent w/w. (This is now being done by Northeast Electronics Corporation.)

Many other possibilities exist for the use of the meter with other types of probes and for the single probe in trees, poles, bridges, houses, and a wide variety of wood products. The details of these uses must come from additional research.

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Acknowledgments

Many people helped in various ways in developing this meter, probe, and method. Their help is gratefully acknowledged: Dr. H. Richard Skutt and Ronald M. Lessard for developing the first pulsed current meter; Dr. Terry A. Tattar for determining how the meter detects decay; and for field testing, Mr. George Saufley, Thomas Chase, Michael Comer, Charles Cragin, and Jonathan Carter. The authors thank Mr. Harold Wochholz and Thomas Dors, and Northeast Electronics Corporation of Concord, New Hampshire for supplying meters and financial support that made it possible to field test the method. Norman Hudson and Edgar Killian supplied hemlock logs for special studies. The Sewall Company of Old Town, Maine, supplied crews and trees for special studies. Mr. Frank Singer operated the University of New Hampshire sawmill for special studies.

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by Paul E. Sendak

ANALYSIS OF PURE MAPLE SYRUP CONSUMERS

UNIVERSITY
1974

USDA FOREST SERVICE RESEARCH PAPER NE-295
1974

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ABSTRACT

Virtually all of the pure maple syrup production in the United States is in the northern states of Maine, Massachusetts, Michigan, New Hampshire, New York, Ohio, Pennsylvania, Vermont, and Wisconsin. Pure maple syrup users living in the maple production area and users living in other areas of the United States were asked a series of questions about their use of pure maple syrup and their responses were compared. User attitudes toward the product, syrup-use patterns, syrup-packaging characteristics, and syrup-purchasing patterns are identified and discussed.

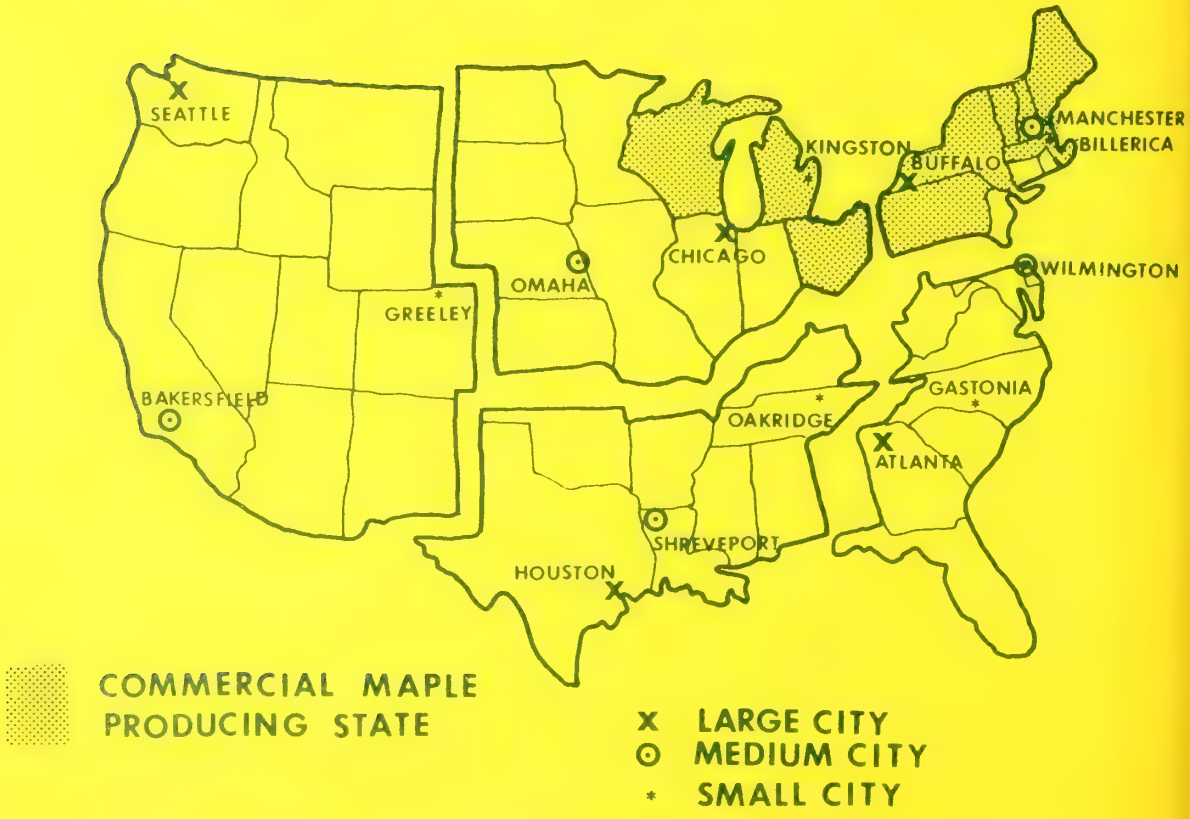

Figure 1.—Location of cities sampled in the pure maple syrup consumer survey.

MAPLE SYRUP—the 100 percent pure product processed from the sap of the sugar maple tree—is commercially made only in North America. The bulk of the pure maple syrup market is still supplied by independent farmers, some of them still using the time-honored techniques and equipment of their fathers and grandfathers who lived when 'sugarin' was commonplace.

Much of the research in the maple sugar industry has been concerned with these producers and their methods of production. Little attention has been paid to the final consumer of the product. To help the producer understand the consumer market we conducted a national survey of pure maple syrup users. The results of the study should serve as a primary source of information for making syrup-marketing decisions and initiating future syrup-marketing research.

The intent of the study was to identify: (1) consumer preference for pure maple syrup, (2) consumer preference for retail syrup packaging and, (3) consumer syrup purchasing patterns.

STUDY METHOD

The United States was divided into five geographic divisions: Northeast, Southeast, South, Midwest, and West (fig. 1). Within each division three cities were randomly selected—a large Standard Metropolitan Statistical Area (S.M.S.A., with a population of one million or more); a smaller metropolitan area (population 50 thousand to one million); and a city not included in an S.M.S.A. and having less than 50 thousand inhabitants.

In each sample city, randomly selected telephone numbers were called. In each answering household the interviewer determined if pure maple syrup was used in the past 12 months by asking the respondent to bring the container of syrup to the phone. If the respondent did not have the container of syrup, a series of questions were asked to determine if pure maple syrup was used. An interview averaging about 18 minutes in length was then administered to only those households where pure maple syrup was used. Housewives were interviewed because they make most of the family food purchases and plan and prepare most of the meals. All interviews were conducted by a national marketing survey firm in August and September 1971.

An initial subsample of 300 phone calls was made in each sample city to estimate the proportion of pure maple syrup users. The remaining sample was apportioned on the basis of these estimates of pure maple syrup use and resulted in a national sample of 1431 respondents. Most of the sample (77.4 percent) fell in the Northeast and Midwest divisions, which contain the commercial maple producing area and have the highest proportion of maple syrup users. The sample was about equally divided among large, medium, and small cities. Two-thirds of the sample was in states reporting commercial maple production (table 1).

Table 1.—*Allocation of national maple user survey sample by geographic division, city size, and in relation to maple-producing area*

Classification	Percent of sample
Northeast	46.2
Southeast	8.3
South	3.5
Midwest	31.2
West	10.8
Total	100.0
Large metro area	32.6
Smaller metro areas	28.9
Cities not in metro area	38.5
Total	100.0
Locations inside the maple area	67.2
All other locations	32.8
Total	100.0

MAPLE PRODUCING AREA VERSUS REMAINING AREA

Virtually all of the commercial pure maple syrup produced in the United States is made in the northern states of Maine, Massachusetts, Michigan, New Hampshire, New York, Ohio, Pennsylvania, Vermont, and Wisconsin (fig. 1). Most of the pure maple syrup produced and sold as table syrup is sold in these states. This area of local markets, corresponding to the area of commercial production, is the most important area to the maple producer. The four cities of Billerica, Buffalo, Kingston, and Manchester are located in the area of local markets.

The remaining 11 cities in the study were located outside of the commercial maple-producing area and were defined as distant markets. For purposes of analysis the data were stratified by location of the sample city relative to the area of commercial maple production.

Incidence of pure maple syrup use is defined as the ratio of the number of households in which pure maple syrup was used to the total number of households contacted in the survey. Expressed as a percentage, the overall incidence of use of pure maple syrup was estimated to be 7.5 percent. In the maple area, incidence of use was about 18.3 percent; outside of the maple area it was about 4.4 percent.

Incidence was estimated by stratifying the total population in a geographic division into population living in large S.M.S.A.s, all other S.M.S.A.s, and all of the remaining population.[1] The incidence of use observed in the survey corresponding to these population strata were assumed to be representative of the geographic divisions. The observed incidences were then weighted by the number of people within each stratum, yielding an estimate of incidence for the whole geographic division.

The maple area was defined to include nine northern states. Maple production in some of these states is restricted to only a few counties. However, with two exceptions, the entire state was assumed to be a part of the maple area. The two exceptions are the New York and Philadelphia S.M.S.A.s. These two large population centers border the non-maple producing area and are located far from the areas where most of the maple syrup is produced in New York and Pennsylvania. The incidence of maple use observed outside the maple area was felt to be more representative of these S.M.S.A.s than that observed in the maple area.

[1] U.S. Bureau of Census, Census of Population: 1970, General Population Characteristics, Final Report PC (1) B1, United States Summary.

PURE MAPLE SYRUP USER CHARACTERISTICS

Age, Household Size, Number of Children, and Income

Housewives interviewed in the maple area were slightly younger than housewives interviewed outside the maple area. The modal age class in the maple area was 35 to 44 years and outside the area it was 45 to 54 years. There was a smaller percentage of one- and two-member households interviewed in the maple area (36 percent) than interviewed outside the area (44 percent). A greater percentage of households interviewed in the maple area had children between the ages of 6 and 12 (32 percent) than did households interviewed outside the area (24 percent). The modal income class was $10,000 to $14,900 for families interviewed in both areas, but there was a smaller percentage of respondents in the $10,000 and over income range in the maple area than there was outside the area. More detailed information on user characteristics can be found in tables in the Appendix.

Data from the 1970 Census were available for the 10 Standard Metropolitan Statistical

Areas in the survey.[2] In both the Buffalo and Manchester S.M.S.A.s Census data indicate that the modal age class for females age 20 years or older was 45 to 54 years. This was just above the modal age class of 35 to 44 years observed in our survey for housewives interviewed in the maple area. However, participants in the Buffalo and Manchester areas accounted for only half of the sample in the maple area. Kingston and Billerica account for the other half of the sample, and Census data were not available for these cities.

In all of the eight S.M.S.A.s outside of the maple area, the Census data indicate that the modal age class for females age 20 years or older was 25 to 34 years. This is two age classes below the modal class of 45 to 54 years observed for housewives interviewed to our survey outside the maple area. Participants in these eight S.M.S.A.s account for about 80 percent of our survey sample outside the maple area.

Comparisons of average household size for the 10 S.M.S.A.s between the survey data and the Census data indicate little difference, especially if Shreveport and Atlanta are excluded because of the very small sample observed there. The Census data indicate an average household size varying between 3 and 3¼ persons. In our survey the average household size ranged between 3 and 3½ persons.

Income data obtained in our survey were not directly comparable to the Census income data. In our survey, participants were only required to indicate the income class which contained their income. In the Census actual income is obtained, and the mean and median incomes are calculated. For the maple area, the mean Census incomes for Buffalo and Manchester fell within the modal income class of $10,000 to $14,000 observed in our survey. The same was true for the mean incomes of six of the eight S.M.S.A.s outside the maple area. However, the mean incomes given by the Census report for Bakersfield and Shreveport were just below the lower limit of the modal income class observed in the survey.

It is difficult to generalize about the differences between the populations of maple users observed in our survey within the maple area and outside this area. Compared to available Census data, our sample of maple users appears to be representative of the general populations in these areas, although our sample size in each city is relatively small.

[2]U.S. Bureau of Census, Census of Population and Housing, Census Tracts, Final Reports PHC(1)–14; –18; –35; –43; –89; –124; –153; –195; –197; –234

ATTITUDE TOWARD PURE MAPLE SYRUP

Respondents[3] were asked to consider if each of five characteristics was very important, somewhat important, or not at all important to their use of pure maple syrup. The characteristics of pure maple syrup were: It has a unique flavor, it is convenient to purchase (available where you usually shop), it is a traditional American food product, it is a natural food item, it is available year-round. There was little difference in the frequency and order of ranking between areas. Ranked according to how often they were considered very important by all respondents combined the characteristics are:

(1) Has a unique flavor (79.7 percent of the respondents)
(2) Is a natural food item (58.3 percent of the respondents)
(3) Is available year-round (57.5 percent of the respondents)
(4) Is convenient to purchase (54.3 percent of the respondents)
(5) Is a traditional American food product (41.5 percent of the respondents)

The results of the survey indicate that there is considerable use of other syrups and toppings among pure maple syrup users. Only

[3]Respondents were housewives who used pure maple syrup and were interviewed in this survey.

sumption of pure maple syrup per using household was about 2¾ pints in 1971.
In summary:

- All respondents used pure maple syrup as topping on other foods but few used it for cooking, baking, or candymaking.
- Maple syrup is used more frequently and consistently year-round per household in the maple area than it is outside the area (table 5).
- Estimated average annual pure maple syrup consumption for households purchasing maple syrup in the 12 months preceding the survey was about 2¾ pints.

MAPLE SYRUP PACKAGING

Packaging in the retail food distribution system has become almost as important as the food product itself. The package must meet certain minimum functional requirements for protecting the contents, it must not be deceiving to the consumer, it must carry certain informational labeling, and it is usually used to advertise and promote the contents.

There are three main types of pure maple containers—tin, glass, and plastic. Plastic containers are fairly new and the data indicate little syrup is packed in plastic (table 6). Only about 4 percent of the respondents indicated that they purchased pure maple syrup or received it as a gift in a plastic container.

The metal syrup can with its bright lithographed maple sugaring scene has been the traditional retail package for pure maple syrup. The metal syrup can still accounts for the largest share of the retail syrup market in the maple area. However, the glass container is the predominant pure maple syrup container outside the maple area.

In the maple area 56 percent of the respondents purchased syrup in a tin container compared to 30 percent outside of the area.

Table 6.—*Type of maple syrup container most recently purchased or received as a gift*

Type	Percentage	
	Maple area	Other area
Metal	55.9	30.2
Plastic	4.3	3.5
Glass	39.8	66.3
Basis: Total number of respondents	954	463

Forty percent of the respondents in the maple area purchased syrup in a glass container compared to 66 percent outside the area.

When asked for their preference for a container a marked deviation from purchasing behavior was apparent. In the maple area, 50 percent of the respondents said that they prefer glass and almost 25 percent said that they prefer plastic (table 7).

Table 7.—*Type of maple syrup container preferred*

Type	Percentage	
	Maple area	Other area
Metal	25.3	16.1
Plastic	24.5	23.2
Glass	50.2	60.7
Basis: Total number of respondents	916	453

Outside the maple area glass was the most frequently purchased container type. Almost 61 percent of the respondents said they preferred glass compared to over 66 percent who said they now purchase in glass. Only 16 percent of the respondents preferred the metal container. Again, over 23 percent of the respondents indicated a preference for a plastic container.

Size of container purchased or received as a gift differed between areas. In the maple area, the most frequently purchased size is the gallon, followed by the quart and the pint. Outside of the maple-producing area the most frequently purchased sizes are the pint, the quart, and the half pint (table 8).

Sendak, Paul E.
1974. **Analysis of pure maple syrup consumers.** NE
Forest Exp. Sta., Upper Darby, Pa.
11 p., illus. (USDA Forest Serv. Res. Pap. NE-295

Users of pure maple syrup who live in the syrup-produc
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g area differ from consumers in other parts of the United
ates in their pattern of syrup use and purchase. This
rvey analyzes differences in user attitudes and habits
d in the packaging and distribution of syrup.

Table 8.—*Size of maple syrup container usually purchased or received as a gift*

Size	Percentage	
	Maple area	Other area
½ pint	4.6	17.2
¾ pint	2.7	9.0
1 pint	19.4	34.6
1½ pints	3.0	4.7
1 quart	26.4	19.6
½ gallon	13.8	6.9
1 gallon	28.1	6.5
Other	2.0	1.5
Basis: Total number of respondents	955	465

There was little dissatisfaction expressed over available sizes. The wide range of sizes shown in Table 8, apparently permits users to purchase the size they prefer.

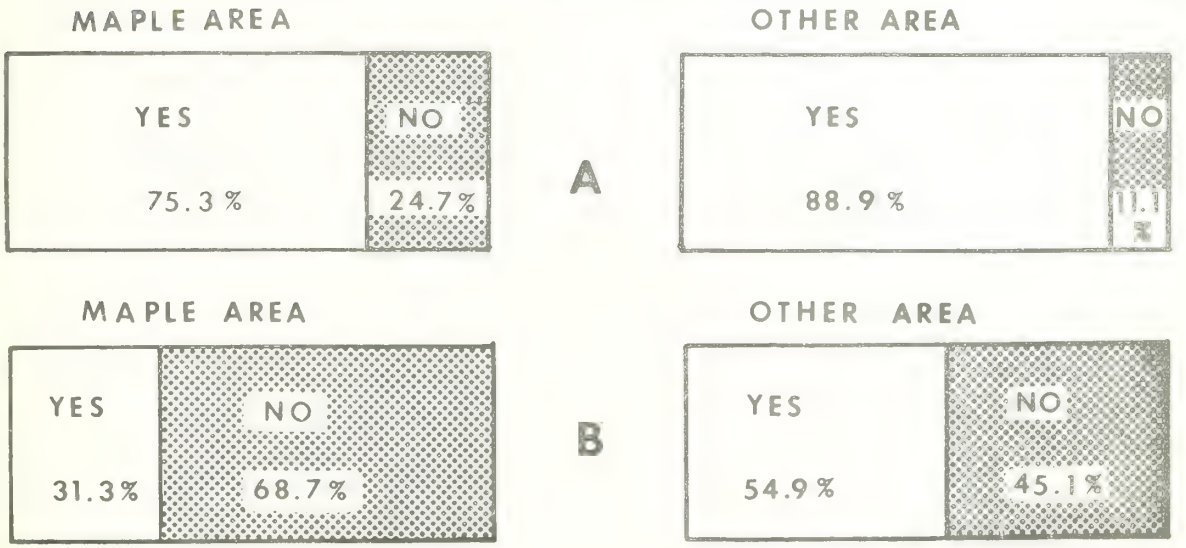
Because the flavor of pure maple syrup is associated with the color of the syrup, the consumers were asked if they would like to see the syrup through the container. Seventy-eight percent in the maple area and 85 percent outside the area said they would, implying preference for a clear glass or plastic container.

A majority of the respondents, 65 percent in the maple producing area and 61 percent outside the area, said that they prefer to see the container illustrated with a maple sugaring scene. A scenic label depicting the unique production process of pure maple syrup may help promote product use.

Finally some questions were asked about the utility of maple syrup containers. Replies were largely a function of container size. In the maple-producing area, where large containers predominated, the retail container was used less often for storage of syrup and as a table dispenser. Outside of the maple producing area, where smaller containers predominated, these uses were more frequent (fig. 2). In summary:

- The metal syrup can still accounts for the largest share of the retail pure maple syrup market in the maple area (table 6).
- Maple syrup was purchased in larger containers in the maple area than outside the area.
- Respondents in both areas expressed a desire for more syrup to be packaged in plastic and respondents in the maple area also expressed a desire for more syrup to be packaged in glass.

Figure 2.—Use of retail maple syrup container for storage of syrup (A) and as a table dispenser (B). Basis: Total number of respondents in the maple area, 953; other area, 466.



usual food purchases adds to the potential for expansion in this market.

The other types of markets, such as the specialty foods shop, mail order, and roadside stand outside the maple-producing area should not be overlooked. Although they represent a smaller total potential sales volume to the industry, as an outlet for one or a few producers in any one area the potential may be great. In these markets pure maple syrup may be promoted to best advantage as a health or natural food and a fancy food product.

From a marketing perspective, one of the most important results obtained from the survey is the determination of the low incidence of product usage. This is most likely the result of inadequate syrup supply. But it also indicates that expansion of the maple syrup industry will not be hampered by lack of potential markets. However, the choice of markets for expansion should be carefully made to maintain product price.

Based on a limited comparison of survey and Census data for age, family size, and income, the sample of pure maple syrup users is fairly representative of the general population of the 10 S.M.S.A.s surveyed. The one exception was the higher modal age class observed in the survey for housewives outside the maple producing area relative to the general population in that area. The survey did not analyze user characteristics by the different types of retail outlets.

Consumers purchase pure maple syrup predominantly for its unique flavor to complement other foods, usually as a topping. Therefore, the supplier should be certain that the syrup he sells meets the quality and preference requirements of the consumer. Marketing focuses on the consumer and should function as the line of communication between consumer and seller or producer.

Although the user of pure maple syrup may want to use pure maple for all of his syrup needs, very few of them do. Our survey indicates that pure maple shares the consumer's syrup requirements with maple-cane syrup blends and other toppings. This is also an indication of short supply, restricted availability, and the significantly higher price of pure maple syrup.

Respondents were not satisfied with the available syrup containers. This should prompt producers and packagers to experiment with different containers. "An effective package is a selling tool; it is imbued with psychological power that is used for motivating consumers, for promoting confidence in the product or brand."[6]

Although "unique taste" was quoted most often by respondents as very important in their decision to purchase pure maple syrup, the unique and colorful production process and the long history of production should also be considered as a means of consumer motivation. The package is a logical choice for utilizing this source of motivation and the lithographed syrup can was a good application of this concept. Therefore, when considering new packaging, it would be advantageous to emphasize the production process and its history rather than to simply emulate the modern packages developed for the common blended syrups.

Marketing cost and risk vary among markets. Selling in a market with large potential sales such as through retail grocery stores and supermarkets may require a cooperative effort among several large producers. New channels of distribution will have to be opened, retailers will have to be educated about the product, and product advertising and promotion may be necessary. Market intermediaries such as brokers, wholesalers, or formal marketing cooperatives may take over these marketing tasks as product distribution becomes more sophisticated.

The lower costs and risks of marketing in potentially smaller markets might be more attractive to other producers. For example, a producer's own roadside stand avoids distribution cost and allows complete control over sale of the product. Selling through specialty food stores, a producer will incur a distribution cost but avoids the costs and risks associated with maintaining his own retail sales outlet. Sales of his product may

[6]Cheskin, L. *Secrets of Marketing Success* (New York: Trident Press) 1967. 278 pp.

also indirectly benefit from the general advertising and promotion carried out by the specialty food store.

Numerous marketing alternatives are open to the individual producer. Each producer must carefully evaluate the alternatives available to him in light of his objectives as a maple syrup producer or seller. He should be careful to include all of the costs and risks for each alternative before making a decision.

APPENDIX

Table 11.—*Percentage of participating housewives in each age class*

Age class	Percentage	
	Maple area	Other area
Less than 20 years	.5	1.5
20-24 years	4.8	7.5
25-34 years	23.2	20.3
35-44 years	23.7	17.1
45-54 years	17.1	21.3
55-64 years	16.0	18.3
More than 64 years	14.6	14.1
Basis: Total number of respondents[a]	952	469

[a]The total number of respondents in the survey was 1431, however, the total number of respondents in each table may not equal that number because of nonresponse to particular questions.

Table 12.—*Size of participating households*

Number in household	Percentage	
	Maple area	Other area
1	5.6	7.6
2	30.8	35.9
3	17.2	15.7
4	19.0	18.2
5	10.9	13.1
6	8.3	4.9
7 or more	8.2	4.6
Basis: Total number of respondents	941	465

Table 13.—*Number of children by age groups*

No.	Percentage	
	Maple area	Other area
UNDER 6 YEARS		
None	74.7	75.5
1	14.4	14.7
2	7.9	8.3
3	2.2	1.5
4 or more	.8	.0
6-12 YEARS		
None	68.0	75.5
1	14.9	11.7
2	11.2	7.7
3	4.8	2.6
4 or more	1.3	2.5
13-19 YEARS		
None	72.4	74.7
1	13.4	14.0
2	9.3	8.5
3	3.4	1.9
4 or more	1.5	.9
Basis: Total number of of respondents	961	470

Table 14.—*Gross annual family income*

Income class	Percentage	
	Maple area	Other area
Under $5,000	17.8	17.3
$ 5,000 - $ 7,499	12.6	15.3
$ 7,500 - $ 9,999	25.3	17.3
$10,000 - $14,999	29.8	23.4
$15,000 - $19,999	10.0	15.0
$20,000 and over	4.5	11.7
Basis: Total number of respondents	708	359

The Author

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MANUSCRIPT RECEIVED FOR PUBLICATION 1 FEBRUARY 1973

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MAYAPPLE

(*Podophyllum peltatum* L.)

by Arnold Krochmal
Leon Wilkins
David Van Lear
Millie Chien

USDA FOREST SERVICE RESEARCH PAPER NE-296
1974

NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

ABSTRACT

The mayapple (*Podophyllum peltatum* L.), long used in folk medicine, was studied to seek more information about its characteristics and potentialities. The plant and its distribution, site soils, and botany are described. Efforts to germinate seed were unsuccessful. Some notes on chemical properties and biological action.

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The work reported here was begun as a project of the USDA Forest Service, Northeastern Forest Experiment Station, at Berea, Kentucky, and carried on at Auburn, Alabama, and Chapel Hill, North Carolina.

RECEIVED FOR PUBLICATION 6 OCTOBER 1973

BEGINNING in 1969, as part of a program to determine the cultural requirements of wild plants that have recognized medicinal value, we undertook to learn as much as possible about the mayapple.

The mayapple (*Podophyllum peltatum* L., family Berberidaceae), had an important place in the primitive medicine of the American Indians and early settlers. The plant was used to treat certain kinds of warts. The root resin was used to treat cancers. The roots were also used to treat jaundice, fever, liver ailments, and syphilis (*2*).

The mayapple is still used today in the folk medicine of the Appalachian Region. A tea made from the roots is used to treat constipation (*1*).

The plant may find a place in modern medicine. Studies are under way to determine whether derivatives from the mayapple have value for treatment of cancer, tumors, and virus (*7, 8*).

DISTRIBUTION

The mayapple is found from Massachusetts south to northern Florida and as far west as Texas and Oklahoma. Although it prefers shady, humid forest areas, it may also be found in scattered populations in areas of higher light intensity at the edges of forests.

SOIL

We analyzed the soil and inventoried the flora of a typical forest mayapple habitat in the Raccoon Creek area of the Daniel Boone National Forest, Jackson County, Kentucky, in July 1970. The site was hilly, heavily vegetated, shaded, and moist; and a small stream ran through the area. A variety of associated plants were found on the site (table 1).

The soil was a typical southern Appalachian cove soil, with alluvial and colluvial material.

Table 1.—A list of plants found growing in association with mayapple in the Raccoon Creek area of the Daniel Boone National Forest, Kentucky

ACANTHACEAE
Ruellia caroliniensis (Walt.) Steud.

ACERACEAE
Acer spicatum Lam.

ANACARDIACEAE
Rhus glabra L.
Rhus radicans

ANONACEAE
Asimina triloba (L.) Dunal

APOCYNACEAE
Apocynum androsaemifolium L.

ARACEAE:
Arisaema triphyllum (L.) Schott
Symplocarpus foetidus (L.) Nutt.

ARISTOLOCHIACEAE
Asarum canadense L.

ASCLEPIADACEAE
Asclepias syriaca L.
Convolvulaceae spp. L.

ASTERACEAE:
Ambrosia trifida L.
Coreopsis major L.
Erigeron spp.
Eupatorium perfoliatum L.
Krigia biflora (Walt.) Blake
Veronia spp.

BALSAMINACEAE
Impatiens biflora Willd.

BORAGINACEAE
Hackelia spp.

CAPRIFOLIACEAE
Viburnum acerifolium L.

CORNACEAE
Cornus florida L.
Nyssa sylvatica Marsh.

CORYLACEAE:
Alnus crispa (Ait.) Pursh.
Alnus serrulata (Ait.) Willd.
Betula lenta L.
Carpinus caroliniana L.

ERICACEAE:
Chimaphila maculata (L.) Pursh
Gaultheria procumbens L.
Gaylussacia spp.
Oxydendrum arboreum (L.) DC.
Rhododendron arborescens L.

FABACEAE
Cercis canadensis L.
Robinia pseudoacacia L.
Schrankia uncinata Willd.

FAGACEAE:
Fagus spp.
Quercus alba L.
Quercus velutina Lam.

GERANIACEAE
Geranium maculatum L.

HAMAMELIDACEAE:
Hamamelis virginiana L.

HIPPOCASTANACEAE
Aesculus octanda Marsh.

IRIDACEAE
Iris cristata Ait.

LAMIACEAE:
Prunella vulgaris L.
Salvia officinalis L.
Scutellaria lateriflora L.

LAURACEAE
Sassafras albidum (Nutt.) Nees

LILIACEAE
Chamaelirium luteum (L.) Gray
Lilium canadensis L.
Smilacina racemosa Desf.
Smilax glauca Walt.
Streptopus spp. Michx.
Uvularia perfoliata L.

MAGNOLIACEAE
Liriodendron tulipifera L.

OPHIOGLOSSACEAE
Botrychium virginianum (L.) Sw.

ORCHIDACEAE
Cypripedium calcelous L.

PASSIFLORACEAE
Passiflora incarnata L.

PHYTOLACCACEAE
Phytolacca americana L.

PINACEAE
Tsuga canadensis (L.) Carr.

PLANTAGINACEAE
Plantago rugelii L.

PLATANACEAE
Platanus occidentalis L.

POLYGALACEAE
Polygala senega L.

POLYPODIACEAE
Adiantum pedatum L.
Dryopteris austriaca intermedia (Muhl) Morton
Polystichum acrostichoides (Michx.) Schott

RANUNCULACEAE
Hydrastis canadensis L.
Xanthorhiza simplicissima Marsh

ROSACEAE
Amelanchier laevis Weig.
Crataegus spp.
Rubus spp.

RUBIACEAE
Galium aparine L.
Mitchella repens L.

SALICACEAE
Salix nigra Marsh.

SAXIFRAGACEAE:
Heuchera puberula Mackenzie & Bush
Hydrangea adorescens L.

SOLANACEAE
Solanum carolinense L.

Table 1.—Continued

UMBELLIFERAE
Cicuta maculata L.
Daucus carota L.

VIOLACEAE
Viola cucullata Ait.

VITACEAE
Parthenocissus vitacea Planch.
Vitis vulpina L.

Table 2.—Description of soil-sampling sites, Raccoon Creek, Daniel Boone National Forest

Sample no.	Description
1.	Roadside Heavy shade 11 plants A-1, 2 inches thick
2.	Hillside Dense shade A-1, 2 inches thick 30 percent slope
3.	Partially sunny glade in forest 0 population 30 percent slope
4.	Bottomlands Dense shade Flat area Top soil Deeper
5.	Intense shade 0 population Bottomland Flat as No. 4
6.	Slightly open glade, foot of white oak as No. 5. Small population with some fruit
7.	Same as No. 6 0 population
8.	Large population Intense shade Little sunlight Bottomland
9.	Intense shade Large population, some drier appearing Shallow A-1 layer
10.	Intense shade Undergrowth Trees Large population

Table 3.—Chemical analysis of soils along Raccoon Creek, Jackson County, Kentucky, site of plant survey

Sample no.	P*	Ca**	Mg	K	C	O.M.
			ppm		*Percent*	*Percent*
1	0.7	470	120	188	1.48	2.54
2	.7	540	90	220	.27	.46
3	1.0	360	90	195	2.14	3.68
4	1.2	230	120	150	2.57	4.42
5	1.7	320	90	170	2.03	3.49
6	1.0	380	85	300	.31	.53
7	1.7	480	80	160	2.34	4.02
8	1.9	200	80	125	1.95	3.35
9	1.7	400	80	145	2.18	3.75
10	1.9	200	90	150	1.68	2.89
Average	1.4	358	93	180	1.87	2.91
Average minus No. 4 & No. 6	—	—	—	—	2.26	3.75
Range	0.7-1.9	200-540	80-120	125-300	0.27-2.57	0.46-3.75

*P extracted with Brays No. 1 solution, using 1:5 soil-extracting sol ratio. This gives available P.
**Ca, Mg, and K extracted with *N* NH_4OAc (ph 7.0). Also 1:5 soil-extracting sol ratio.

A thick litter of humus was not included in the sampling. Our samples came from sites both with and without mayapple plants (table 2).

The analyses (table 3) indicated that plant-available P in the A horizon was low when compared to agricultural soils in the region. However, the soil probably contains enough P for vigorous plant growth, as the thick humus and litter layer contains a reservoir of organic P. Levels of Ca, Mg, and K are adequate for plant growth. Organic-matter levels are typical of forest cove sites of the region.

BOTANY

The mayapple is an erect perennial growing to 2 feet in height, with a solitary or forked stem topped with one or two lobed leaves (fig. 1).

The solitary, creamy white, fragrant flowers vary from 2 to 3 inches across, have six to nine petals (fig. 2), and arise in the v-shaped axil of the stem (fig. 3).

The roots are rhizomatous and grow close to the soil surface. Individual plants occur at the nodes to form dense clonal communities (fig. 4).

The mature fruits are yellow, 1½ to 2½ inches long, ovoid, and may contain up to 25 seeds, each in a mucilagenous aril (figs. 5 and 6).

The seeds (fig. 7) are dark brown, oval, flattened, tapered at the apex, with a dull brown rough surface and an oval, inconspicuous hilum. As the seeds age, they become wrinkled.

SEED SET

The number of seeds matured by a clone is small in relation to the number of plants. Our observations (fig. 8) lead us to believe that the major form of propagation is vegetative via rhizomes. In several years of field observations in Kentucky and North Carolina, no single plant of seed origin has been seen.

We observed the plants in bloom to seek explanations for the low fruit set and subsequent low seed yield in terms of pollination. We saw an unidentified white moth visiting the flowers. We bagged a number of plants before pollen-shedding and found no fruit set. Unbagged, emasculated plants did set fruits. We con-

Figure 1.—The lobing of mayapple leaves and the variety in number of lobes is shown here.

Figure 2.—A detailed sketch of the floral morphology of mayapple flowers.

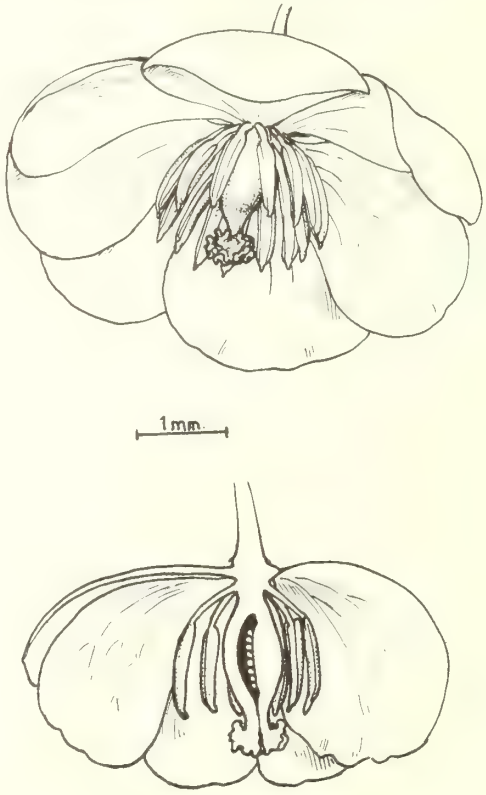


Figure 3.—The large creamy white attractive flowers originate in the v-shaped axils of the bifurcated stems.

Figure 4.—A typical clone originating from a rhizome with both single stem and bifurcated stems, showing the common origin of both kinds of stems.

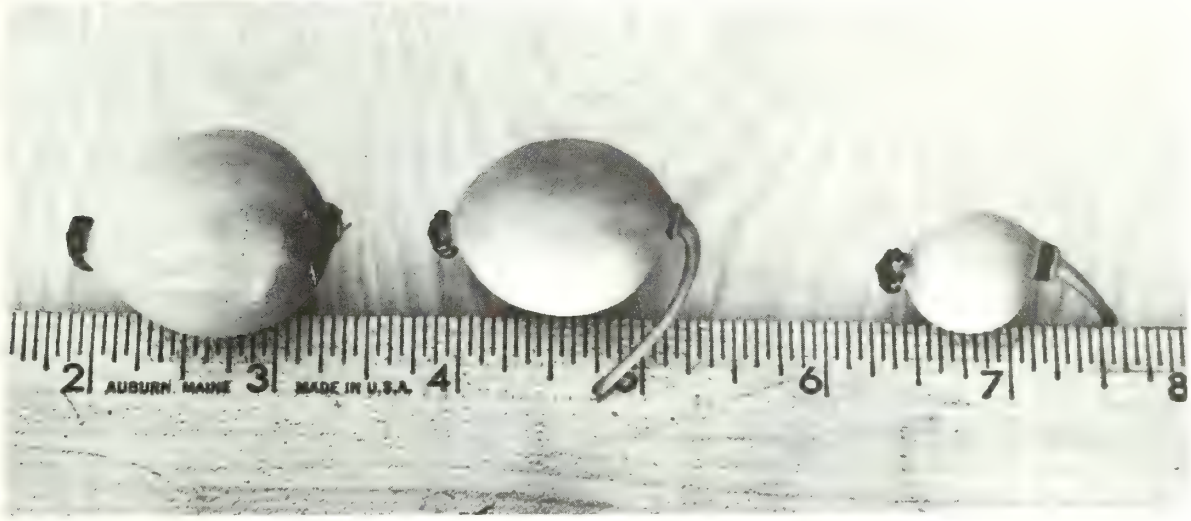


Figure 5.—Typical fruits range from 1 to 1½ inches. The skin is shiny yellow.

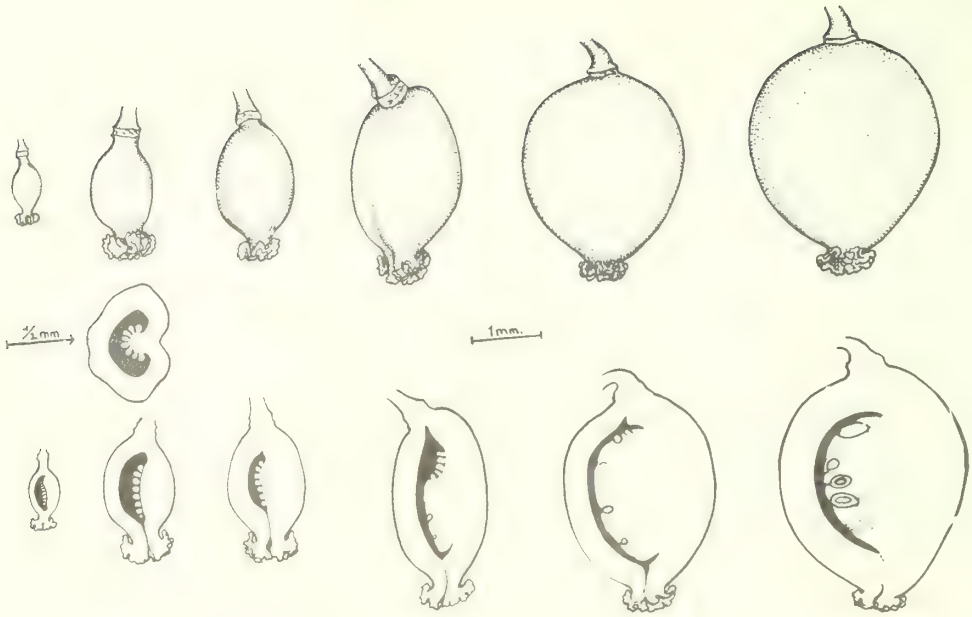


Figure 6.—The external and internal development of mayapple fruits, showing the development of the seed-bearing axils.

Figure 7.—Top sketches show the fresh, plump, dull brown seed and the hilum. The bottom sketches show the embryo, which is large.

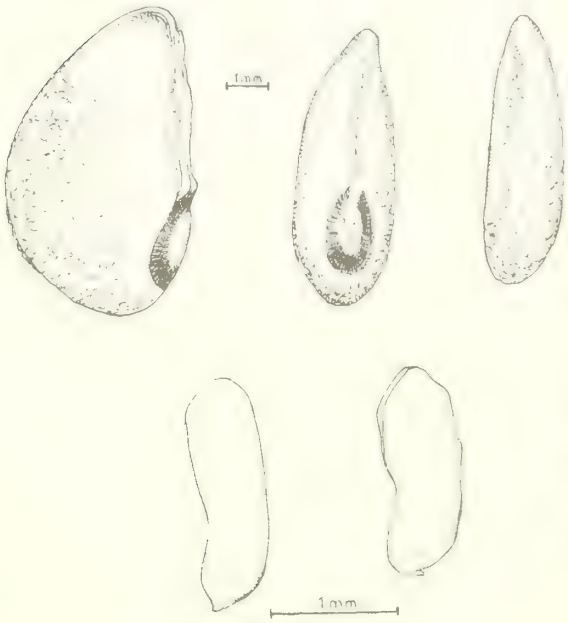


Figure 8.—Typical of the low number of fruits that set are these adjacent plants showing aborted and apparently non-fertilized flowers.

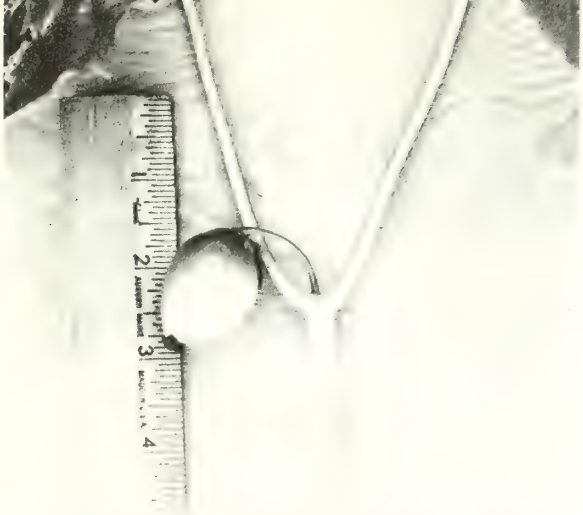
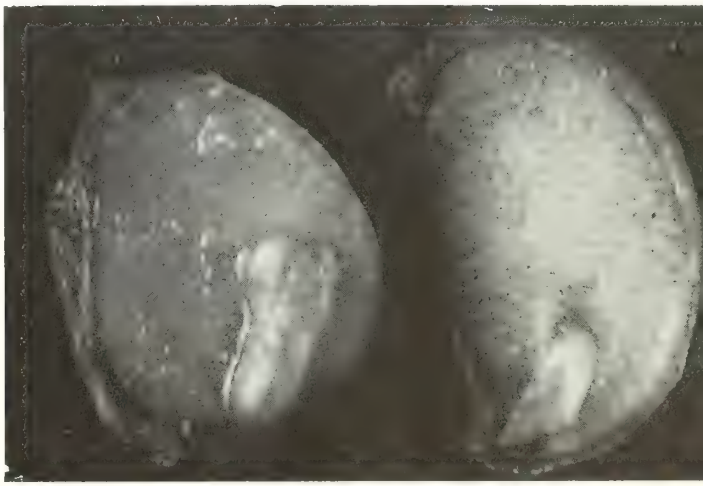


Figure 9.—The standard site of fruit development is in the v of the stem.

Figure 11.—These tetrazolium-treated seeds demonstrates the variable response to the dye. The seed on the left with the plump and well-formed embryo stained pink; the seed on the right failed to stain pink.

Figure 10.—This is the only fruiting single stem plant seeń in Kentucky and North Carolina over a period of several years.

Figure 12.—Excised embryos of mayapple. The embryo on the left, malformed and slightly shrivelled, failed to show any pink; the plump well-shaped embryo on the right turned pink when treated with tetrazolium.



cluded that fruit set depends on cross-pollination from other plants.

We noted that all fruits were set on plants with bifurcated stems (fig. 9), except for one on a single-stem plant (fig. 10). We examined a number of clones and found both types of plants arising from the same rhizome system, at random locations (fig. 4), indicating to us that age of the rhizome was not related to fruiting.

We examined fruiting habit on 446 plants at two different locations in Kentucky in the summer of 1970. Of these plants observed, 13.6 percent were bifurcated and bore fruit; 23.3 percent were bifurcated and bore no fruit; 62.5 percent were single-stem and fruitless. A fruit yield of 13.6 percent is very low.

The very small percentage of plants maturing fruit were also subject to attack by field mice, often observed climbing stalks to eat the fruits.

SEED GERMINATION

We have been unable to germinate the seeds of mayapple. We have tested for seed-coat impermeability, dormancy, presence of phytochrome inhibitors, cotyledonary inhibitors, and response to kinetin. Using tetrazolium (embryos soaked for 24 hours, in 0.1 g tetrazolium salts dissolved in 99 ml water) we have found a positive embryo response for viability, a deep and uniform red color in the embryos and seed (figs. 11 and 12).

An analysis of 6 replicate samples of 25 seeds each, from seed collected in the summer of 1971, showed viability in 80 percent of the embryos when tested with tetrazolium. Twenty percent of the seeds showed faint pink coloration and were considered nonviable.

When tested with tetrazolium, seeds stored for 2½ years at room temperature were apparently all dead; no red color was present in the sampled embryos.

INHIBITORY EFFECTS OF FRUITS

Because our observations showed the seed to be viable, but not germinable, we hypothesized the presence of a germination inhibitor in the fruit.

To test the hypothesis we dried and ground mature fruits and made up a solution of 1 g of powder to 50 ml of water and applied it to bean and corn seed on filter paper in petri dishes. Germination was reduced under such treatment.

We then used a range of concentrations of powdered fruits on seeds of *Avena*. A skewed curve resulted (table 4), showing a significant inhibition of germination at 1,000 ppm concentration. No significant plant weight differences were noted, though top length did decrease at the highest concentration, but was greater than the control.

Table 4.—Effects on growth and germination of Avena treated with differing concentrations of Podophyllum fruit

Treatment	Germination [1]	Average plant weight	Average top weight/plant	Average length tops
	Percent	*g*	*g*	*Inches*
Distilled water	40	.353	0.248	5.21
125 ppm	40	.311	.250	7.33
250 ppm	60	.330	.254	7.84
500 ppm	30	.357	.260	6.33
1,000 ppm	20	.321	.230	6.12

[1] 50 seeds per 2 replicated test used after 2 hours presoaking; germination counted after 10 days at room temperature, with incandescent bulbs.

CHEMISTRY

Thin-layer separations of ripe fruits were obtained (table 5). The ethanol and methanol elutants considered water soluble were tested for germination effects.

The methanol elutant sharply increased germination of *Avena* with a reading for replicated tests of 60 percent; the ethanol resulted in 30 percent germination and the distilled water 40 percent.

Thin-layer separation of the fruits (table 6) showed the methanol elutant to have a different chromatogram than the other materials.

The non-water-soluble elutants have not been tested.

Table 5.—Mature fruit extracts obtained by thin-layer chromatography

Sample* No.	(Wt. of sample) gm. of extract	(Equivalent wt.) gm. of dry powder/ gm. of extract	(Sample represents wt. of powdered drug) gm. of dry powder	Solvent
1	1.0794	18.02	19.12	Petroleum ether
2	.2127	53.30	11.46	Diethyl ether
3	.1094	122.20	13.36	Chloroform
4	.5777	15.90	9.20	Ethanol
5	.7951	15.75	12.42	Methanol
6	.9828	7.53	7.36	Distilled water

*Materials extracted consecutively in the order as listed above.

Table 6.—Thin-layer chromatography of dried mayapple fruits

No. fraction (extract solvent)	R (color under long-wave uv before spraying)		
	Dragendoff's R.	$SBCl_3$ R.	Others
1. (petroleum ether)	0.55 (blue) *	0.30 (blue) +	
2. (ether)	.60 (blue) +	.50 ±	
3. (chloroform)	—	.50 (blue) +	0.65 (blue), .25 (blue)
4. (abs. ethanol)	—	—	.70 (blue)
5. (abs. methanol)	—	—	* .44 (purple), .06 (blue)
6. (water)	—	—	—

Solvent system: benzine : methanol (95:5)
Absorbent: silica gel Ct
Spring reagent: 1 Dragendoff's reagent for alkaloids
2 Antimony trichloride reagent for resins or steroid glycosides
*Eluted by solvent system of benzine: methanol (80:20) with adsorbosil-1 plate.

BIOLOGICAL ACTION

Hartwell and Schrecker (*3*) have summarized the complex chemical compounds of *Podophylum*. They listed 12 lignins and 4 flavonols; and 66 derivatives of podophyllotoxin, one of the lignins.

Desoxyphyllotoxin, one of the lignins, was reported to be highly active in damaging sarcoma in mice (*4*). The resin of the root, referred to as podophyllin, has given good control of venereal warts (*5*). Sullivan and King (*6*) reported anti-mitogenic activity, and Belkin (*7*) and Hartwell and Shear (*8*) reported a destructive effect of podophyllin on cancer cells in experimental animals.

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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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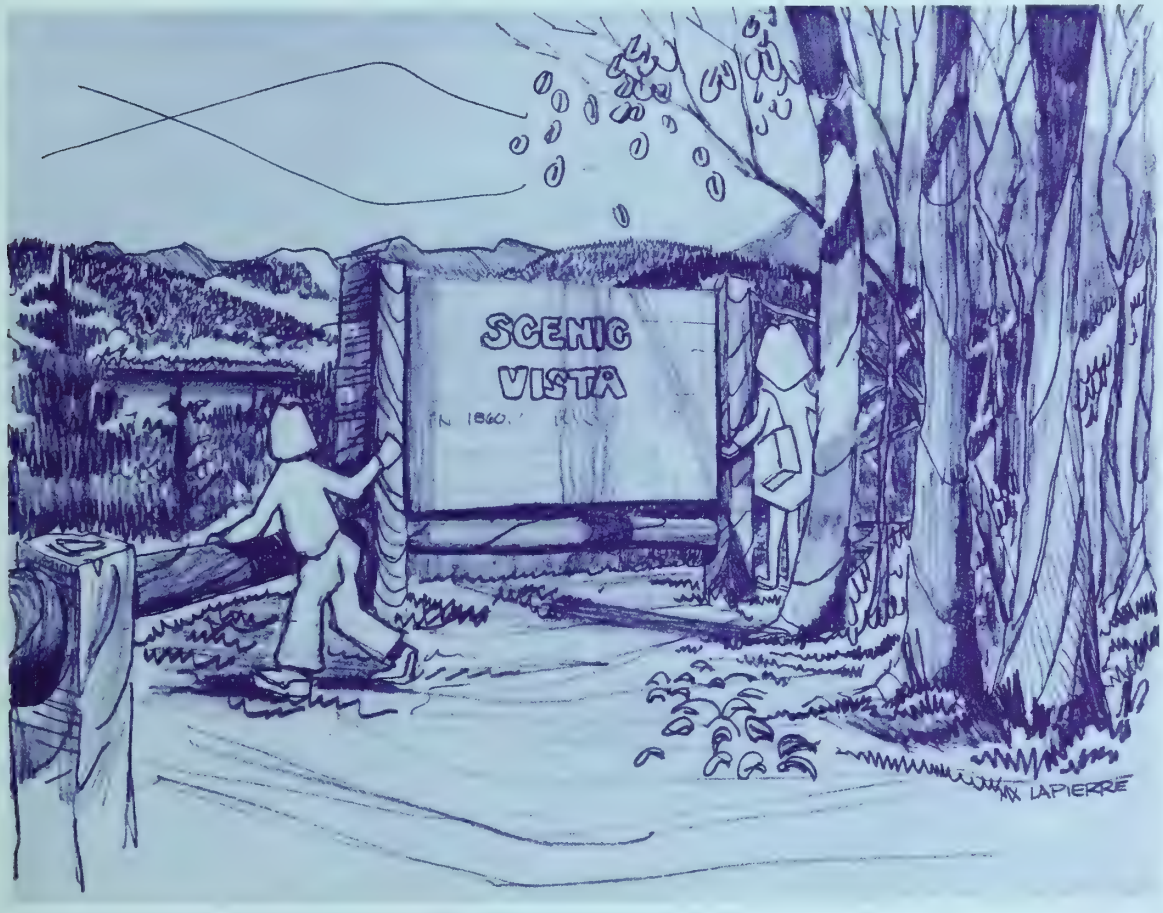
Communicating Rules in Recreation Areas



by Terence L. Ross
and George H. Moeller

USDA FOREST SERVICE RESEARCH PAPER NE-297
1974

NORTHEASTERN FOREST EXPERIMENT STATION
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MANUSCRIPT RECEIVED FOR PUBLICATION 21 JANUARY 1974

Abstract

Five hundred fifty-eight campers were surveyed on the Allegheny National Forest to determine their knowledge of rules governing recreation behavior. Most of them were uninformed about the rules. Results of the study suggest that previous camping experience, age, camping style, and residence significantly affect knowledge of rules. Campers who received rule brochures or saw posted signs had significantly higher scores on knowledge of rules than others. Concentrating communication efforts on adolescents, tent campers, low frequency-of-visit campers, and non-locals might produce immediate gains in knowledge about rules.

TO THE RECREATION-AREA manager, rules are purposeful, valuable, and necessary for the proper maintenance of the environment and for the protection of people. The recreationist, however, does not always recognize the worth of rules, because he does not agree with them, does not understand them, or simply does not know about them. Better methods are needed to tell him what the rules are.

A study was undertaken to determine the degree to which campers actually know about existing rules and to suggest ways for managers to direct their communication efforts to improve knowledge of rules.

STUDY METHOD

Sampling

The study was made at Kiasutha and Red Bridge campgrounds, both located adjacent to the Allegheny Reservoir on the Allegheny National Forest near Warren, Pennsylvania. The two campgrounds, together containing 150 camping units, offer camping and fiishing opportunities. Kiasutha also has boat-launching, picnicking, and swimming facilities.

Camping groups were sampled randomly in proportion to the number of occupied sites in each camping area on a sampling day. Campers selected from camping groups included both adolescents, between the ages of 12 and 17, and adults.

Adults were recognized as potentially influential in conveying knowledge of rules. Therefore, where present, both male and female adult heads of camping groups were used as respondents. If only one group leader was present, a call-back interview was arranged. Where present, one adolescent was selected randomly from the group by listing all adolescents alphabetically by first name and selecting the first as a respondent. Sampling was carried out between 1 July and 14 August 1972.

Campers were approached at their sites following one of the three daily meals. After explaining the study, we gave each respondent a self-administered questionnaire (appendix). The average time required to complete the questionnaire was about 15 minutes. The interviewer remained at the site to answer procedural questions and to discourage collaboration among respondents. From 221 camping groups, 558 responses were obtained.

Brochure Distribution

Brochures listing campground rules were distributed systematically to campers as they entered the campgrounds. A cyclical schedule was used: on 5 days brochures were distributed to arriving campers, and on the following 5 days none were distributed. This procedure insured that a high proportion of the respondents would see the rule brochure.

Study Questionnaire

Two forms of a self-administered fixed-form survey questionnaire were used. The material content of both was identical, but answer categories were reversed to help eliminate potential response bias. Questions were divided into three groups: those to determine respondent characteristics that might influence their knowledge of rules; questions to determine actual knowledge of rules; and questions to determine how much respondents were exposed to posted rule signs and brochures.

Thirteen questions were designed to solicit information about the respondent: activity type (boater/non-boater) age; sex; frequency of past visits to the Allegheny National Forest; previous visits to other national forests; home community (urban/rural); residence (local/non-local); group structure (children/no children); type of camping equipment; camping area (Kiasutha or Red Bridge); exposure to rule brochure (exposed/not exposed); exposure to posted rule signs (exposed/not exposed); and length of visit.

Respondent knowledge of rules was determined by a recreation-rule-knowledge exam (appendix). It consisted of 10 closed-end questions that were derived from rules contained on posted information signs and in rule brochures. The exams were scored by the number of correct responses. *True*, *False*, and *Don't Know* categories were provided. *Don't know* responses were counted as incorrect answers. Questions were arranged so that their order of presentation would not allow respondents to reach an answer based on information contained in preceding questions.

Respondents were instructed not to guess at their answers. They were told that the purpose of the exam was not to measure their knowledge, but to measure the effectiveness of communication efforts; and that speculation would invalidate study results.

Respondent Characteristics

Male and female respondents were represented equally in the sample. No single age group dominated the sample. The largest proportion of respondents (25 percent) were between 25 and 34. Adolescents made up 18 percent of the sample.

Respondents were almost equally divided between boaters and non-boaters. Over half came from urban communities. Only 11 percent of the respondents lived within 25 miles of the campgrounds, but 72 percent lived between 50 and 200 miles. Eighty percent of the respondents sampled were from family groups; 57 percent were in camping groups of 4 to 6.

Nearly half of the respondents had not previously camped on the Allegheny National Forest, and 79 percent had not visited another national forest in the 2 years before the survey.

Forty-one percent of the campers occupied tents. Of the others, 24 percent occupied tent-trailers, 20 percent trailers, 11 percent pickup campers, and 4 percent used mobile campers.

Analysis

Simultaneous chi-square testing procedures were used to test for independence between camper characteristics and rule score distributions. In each test, score distributions were compared for selected camper characteristics. For example, in testing the null hypothesis that sex is independent of rule-knowledge score, respondents were divided into male and female groups, and the score-frequency distributions were compared by using chi-square. The student t-test, with observations paired within camping groups, was used to test for knowledge transfer between adults and adolescents.

Several important points should be kept in mind when reviewing study results. First, the chi-square test itself does not reveal the strength of relationship between rule-knowledge score and an independent variable. The test only reveals where the distribution of scores are statistically different. We use the mean score to supplement relationships implied by the statistical tests of independence. Second, in testing one independent variable at a time (for example, camper characteristic) no attempt was made to control for the confounding effects of other, perhaps intercorrelated, independent variables. Finally, it should be recognized that statistically significant test results do not necessarily imply relationships that are meaningful to the recreation manager.

RESULTS

Knowledge of Rules

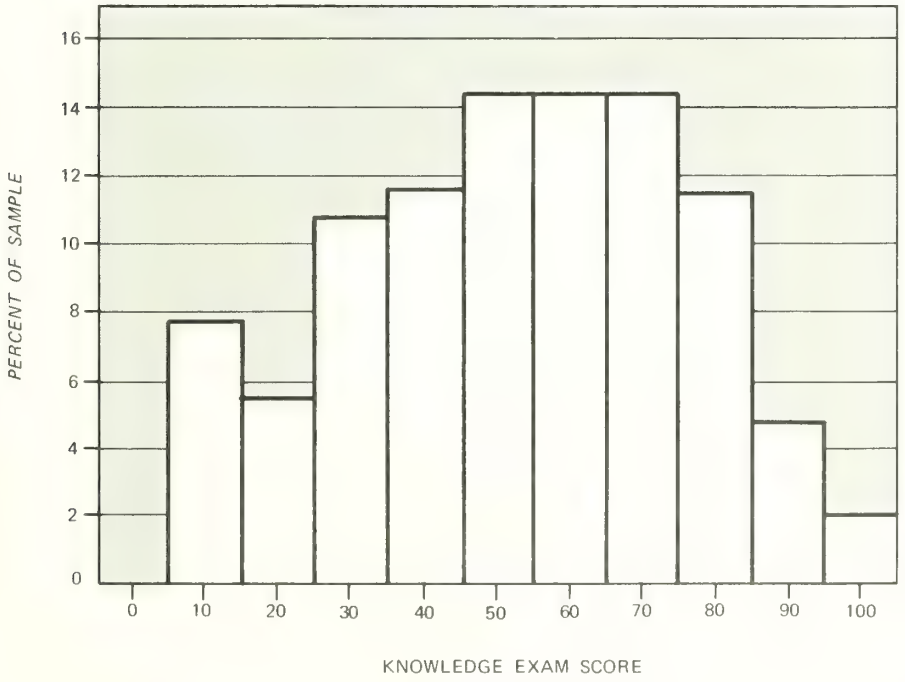
Score distributions for individual exam items are shown in table 1. For all respondents, the mean score for the exam was 49.5. Only 48 percent of the respondents scored 60 or more. Six percent had scores of 90 or 100, while 14 percent had scores of 10 or 20 (fig. 1).

Table 1.—*Response to questionnaire about knowledge of campground rules**

Question	Response	
	Correct	Incorrect
	Percent	*Percent*
1. At all times within camp and picnic grounds, dogs, cats, and other animals must be confined or restrained on a leash. (T).	83	17
2. Because food wastes are decomposable and serve as a food source for many forest animals, they may be deposited on the ground in small quantities. (F).	76	24
3. Clothing or articles of household use may not be washed at hydrants in recreation areas. (T).	68	32
4. Leashed dogs and cats are allowed at developed beaches. (F).	59	41
5. If you have paid in advance for your site, you may leave your camping equipment unattended for more than 24 hours. (F).	56	44
6. Small pack tents may be pitched for evening use in picnic areas after 8:00 p.m. (F).	42	58
7. Even though a limb on a tree appears to be dead, it may not be used as firewood. (T).	41	59
8. A camper may set up and leave his camping unit unoccupied the first night if the site is attended the next morning. (F).	39	61
9. Small motorized bikes may not be operated on roadways within camp areas during daylight hours. (T).	34	66
10. Besides hikers, only bicycles are allowed on trails within developed recreation areas. (F).	20	80

*Letter in parenthesis following question indicates whether question is *True* or *False*.

Figure 1.—Camper knowledge scores as a percentage of the total sample.



Variables Associated with Knowledge Level

Of the variables tested, six were associated with knowledge of rules: age; frequency of visits to the Allegheny National Forest; relation of home to the forest; camping style; exposure to rule brochure; and exposure to posted signs. Variables not associated with knowledge of rules were: activity type; sex; frequency of visits to other national forests; urban/rural residence; group makeup; length of stay when interviewed; and campground sampled (table 2).

Table 2.—*Group mean scores on knowledge of campground rules*

Respondent Group	Group size	Percent of sample	Group mean score
	No.	*Percent*	*Percent*
VARIABLES ASSOCIATED WITH KNOWLEDGE LEVEL			
Age:			
12 to 17 years	100	17.9	38
18 to 24 years	63	11.3	45
25 to 34 years	137	24.5	54
35 to 39 years	68	12.2	51
40 to 49 years	115	20.6	54
50 years or older	75	13.5	56
Number of visits to the Allegheny National Forest over previous two seasons:			
First visit	267	47.6	48
Two to four visits	181	32.4	49
Five to ten visits	51	9.1	50
Over ten visits	59	10.6	61
Relation of home to the Forest:			
Local	63	11.3	61
Non-local	495	88.7	48
Camping style:			
Tent	228	40.8	47
Tent-trailer	132	23.6	53
Trailer	115	20.6	59
Pickup truck camper	64	11.5	43
Mobile camper	19	3.5	33
Exposure to rule brochure:			
Exposed	251	48.5	57
Not exposed	267	51.5	44
Exposure to posted signs:			
Exposed	328	64.6	54
Not exposed	180	35.4	44
VARIABLES NOT ASSOCIATED WITH KNOWLEDGE LEVEL			
Activity type:			
Boater	283	50.7	49
Non-boater	275	49.3	51
Sex:			
Male	279	50.0	51
Female	279	50.0	48
Number of visits to other National Forests over previous two seasons:			
None	441	79.0	49
One	52	9.3	53
Two	20	3.6	56
Over two	45	8.1	51
Residence:			
Urban	326	58.4	49
Rural	232	41.6	52
Group makeup:			
With children	442	79.2	50
Without children	116	20.8	51
Length of stay at time of interview:			
One to three days	283	50.7	52
Over three days	275	49.3	48
Camping area:			
Kiasutha	423	75.8	49
Red Bridge	135	24.2	52

Directing Communication Efforts

The objective of the communication process is to provide a flow of information to a selected audience. If segments of the recreational population demonstrate different levels of knowledge about rules, when all are exposed to essentially the same communication forces, then additional communication efforts should be directed at these segments. Our Allegheny study revealed that the relative success of communicating rules varies between segments of the camping population. Four respondent characteristics were related to knowledge of rules; age; frequency of past visits; relation of home to the Forest, and camping style.

Respondent Age

Knowledge of rules increases with age. Respondents were divided into six age groups ranging from adolescents (12 to 17 years) to adults 50 years or older. Mean knowledge scores for each age group are shown in table 2. From these mean scores, it is apparent that a positive association exists between age and knowledge of rules.

Chi-square analysis was used to compare knowledge-score distributions of adolescents (12 to 17 years) with all adult scores, as well as with each of the adult age groupings. The score distributions were found to differ at the 0.01 level of significance or greater. Thus, our findings indicated that adolescent scores are significantly lower than adult scores. Likewise, the student t-test, with paired observations, revealed no measurable intra-group transfer of rule knowledge between adults and adolescents within the camping group.

A greater proportion of campers could possibly be made knowledgeable of rules if additional communication efforts were directed toward younger age groups. Results indicated that communication efforts might be applied in some inverse ratio to age—particularly for those under 25. If this were done, in the short term the percentage of knowledgeable campers should increase by an increase in adolescent rule knowledge. In the long term, both the percentage of knowledgeable campers and the mean knowledge level of the entire camping population would probably increase.

Frequency of Past Visits

Knowledge of rules also increased as familiarity with the recreation area increased. Campers were classified into four groups based on their frequency of visits to the forest during the two seasons before the study: first visit, 2 to 4 visits, 5 to 10 visits, and more than 10 visits. Mean group scores were found to increase continuously from 48 for first-time visitors to 61 for the over-10 frequency-of-visit group (table 2).

The greatest score increase appeared in the over-10-visit group (table 2). Chi-square analysis disclosed that the increase in knowledge level between frequency-of-visit groups was statistically significant between all groups and the over-10-visit group at the 0.05 level or greater.

Frequency-of-visit comparisons indicated that a greater percentage of campers might be made knowledgeable of recreation rules if additional communication efforts were directed at lower-frequency-of-visit campers. But recreationists who are unfamiliar with the recreation area are not as easily identified as are adolescents.

Relation of Home to Forest

It is more than coincidence that 11 percent of the respondents fell in both the over-10 frequency-of-visit group and in the local-respondent group. The intercorrelation of these two groups is further evidenced by their respective mean scores. Both the over-10 frequency-of-visit group and the local-respondent group has mean scores of 61 (table 2). Therefore the non-local respondent group probably dominates the under-10 frequency-of-visit group. An attempt should be made to distinguish local from non-local campers, because non-local campers represent the majority of recreationists who are unfamiliar with the recreation area and consequently are less informed about rules.

A large difference was observed between the mean scores of local and non-local respondents. Non-local campers, 89 percent of the total sample, had a group mean score of 48, whereas local campers had a mean score of 61 (table 2). Score distributions of local and

non-local respondents differed at the 0.001 level of significance. The percentage of knowledgeable campers could possibly be increased if additional communication efforts were directed toward non-local campers.

Camping Style

Camping style—the type of camping equipment used—was related to knowledge of rules. Campers were divided in five groups by the type of camping equipment they used: tents, tent-trailers, trailers, pickup-truck campers, and mobile campers. Computed mean scores for each group showed that scores varied with camping style (table 2). Respondents using trailers had the highest group mean score, 59; while respondents using mobile campers had the lowest mean score, 33. Statistical analysis further supports this observation. Scores of tent campers were first compared with the scores of all other campers. The knowledge-level distributions of the two groups were found to differ at the 0.10 level of significance. Next, pair-wise chi-square tests were conducted among each of the five camping-style groups (table 3).

Significant differences in score distributions were found between campers who used different types of camping equipment. Previous research has shown that campers progress in their camping styles (*LaPage and Ragain 1971*). It is quite possible that tent-trailer and trailer campers interviewed in this study were formerly tent campers, and consequently are better informed than other campers about the recreation area. This reasoning, however, would not account for the low mean scores of pickup-truck campers and mobile campers, unless these campers are entirely new campers who did not pass through the tent or tent-trailer camping stages.

The most obvious observation that can be derived from these findings is that mobile campers, pickup-truck campers, and tent campers, who comprised 4, 12, and 41 percent respectively of the sample, had significantly lower mean scores than trailer campers and tent-trailer campers. The percentage of knowledgeable campers may be increased by directing communication efforts toward tent campers, mobile campers, and pickup-truck campers.

Table 3.—*Pair-wise chi-square test results: significant camping-style group differences*

Comparison		Significance level
Group	Group	
Tent	Trailer	0.001
Tent	Mobile camper	.01
Tent-trailer	Trailer	.05
Tent-trailer	Mobile camper	.05
Trailer	Pickup camper	.01
Trailer	Mobile camper	.001

Method of Communication

The other variables related to knowledge of rules—exposure to rule brochures and exposure to posted signs—fall into the category of method of communication. Once recreation managers are able to identify the uninformed segments of the recreation audience, the path to enlightenment will lie in employing the most effective method for conveying rules to that audience.

Rule Brochure

Exposure to a recreation-area rule brochure increases knowledge of rules. Roughly half of the respondents recalled that they had been exposed to the rule brochure. Those exposed to brochures had a mean score of 57 as compared to a score of 44 for those not exposed (table 2). Score distributions for campers who were exposed to rule brochures were found to differ at the 0.001 level of significance from those who were not exposed to brochures.

Brochures are an effective means of conveying rules—provided they are distributed systematically. The wording and design of a brochure contribute to its effectiveness as a means of communication. It is possible that different types of recreationists respond differently to a particular brochure design. An effort should be made to match brochure design with the intended audience. Another problem with the effectiveness of brochures is the way in which they are distributed. A distribution system in which the recreation-area entrance attendant delivers a brochure to the driver of the camping vehicle while a group is registering has some serious inadequacies. Better approaches may be needed.

Posted Signs

Like rule brochures, exposure to posted rule signs seems to increase campers' knowledge of rules. In this study, 65 percent of the respondents recalled seeing posted rule signs. The group exposed to posted rule signs had a mean score 11 percent higher than those not exposed (table 2). The score distributions of the two groups differed at the 0.001 level of significance.

Posted signs apparently were read by a large portion of the campers in this study. Because posted signs can be placed strategically (and do not require hand distribution, as brochures do) signs may have a greater potential for communicating rules than brochures do. But their effectiveness can be limited by their placement and design. Care must be taken not to negate the communication value of posted signs by poor wording and placement in such a way as to degrade the esthetic value of the recreation area.

CONCLUSIONS

Our study results support three major conclusions.

First, campers are not well informed about rules. Fewer than half of the respondents in this study got scores of 60 or more on the knowledge-of-rules exam. The overall average score was 49.5. In very few instances would such a low communication-success level be considered satisfactory. Efforts should be made to utilize all communication means available, without disproportionate costs to management, to increase the level of rule knowledge.

Second, analysis revealed four variables that help to identify uninformed campers: age; frequency of past visits to the area; relation of home to the area; and camping style. User characteristics not related to knowledge of rules include: activities participated in other than camping; sex; past visits to other similarly administered recreation areas; residence; group composition; and length of stay.

Third, the differences found in score distributions showed that communication methods can be identified for improving knowledge of rules. Respondents exposed to rule brochures and posted signs had significantly higher scores than those not exposed. Through systematic distribution of rule brochures, knowledge levels may be increased without high cost to management. Design and distribution of posted rule signs could also be improved to increase their effectiveness. If other economically feasible ways to inform people of rules can be found, or if the use of present means can be improved, the proportion of knowledgeable campers could be increased.

RECOMMENDATIONS

Increased Communication Efforts Should Be Directed Toward the Adolescent, First-time, Non-local, and Tent Camper Segments of the Recreation Audience

Specific groups within the user population must be identified. Adolescents and tent campers do not present much of a problem, but non-local and first-time visitors are hard to identify.

Non-local visitors require special attention. One approach, where feasible, would be for the area entrance attendant to identify non-local campers by home address on the registration forms. Visual examination of auto license plates and vehicle registration stickers could also be used. The attendant could ask non-local groups if they are familiar with the area. If not, they could be given brochures to intro-

duce them to the area. At the discretion of the attendant, the group could also be invited to stop at a programmed audio-visual display before going into the area. This procedure would not only direct communication specifically toward groups, but would permit the entire group to be reached rather than only the vehicle driver.

Another approach would be to use selected personal contacts by recreation site administrators. Non-local camping groups could be identified by reviewing registration records. Selected groups could be visited by a site administrator trained in communication methods. His objective would be to familiarize the group with the area and distribute pertinent literature.

Communication Media Should Be Located According to Observed Social Interaction and Activity Patterns

Communication efforts rely heavily on signs at locations that people normally pass. The hope is that they will stop to read the signs. But they don't. Less than half of the sampled campers recalled reading rules posted on signs, although 65 percent recalled seeing the signs. To reach a greater percentage of people, signs should be placed carefully.

In many recreation areas, signs are limited to bulletin boards placed near centrally located toilet and shower facilities. Our study indicated that such bulletin boards are seen by less than half of the campers. It might be beneficial to put signs inside restroom and shower facilities. Most people visit these facilities at least once during their visit, often immediately after they arrive. Signs here would give the visitor an opportunity to familiarize himself with the rules while using the facilities. And signs here would not have a negative impact on the esthetic values of the natural forest environment. They would be easy to maintain and would probably cost less than increasing the number of bulletin boards.

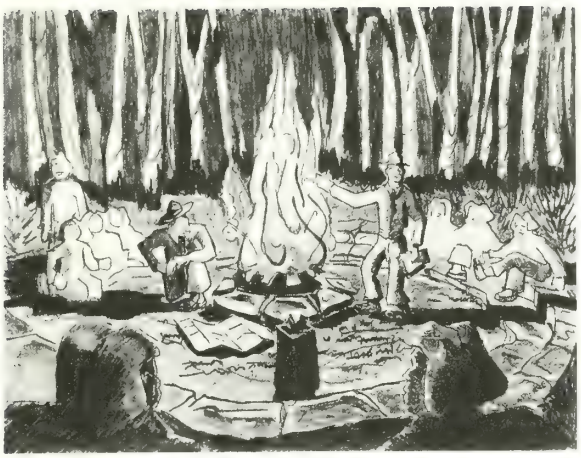
Not that bulletin boards are not effective. Displays of rules do reach a large portion of the camping population (*Wagar 1971*). However, excessive use of them is constrained by the impact they have on the esthetics of an area. We suggest that, rather than increasing the number of bulletin boards, the manager should concentrate on improving sign messages.

In his study of camper activity patterns in auto campgrounds on the Huron-Manistee National Forest, King (*1965*) found that nearly 70 percent of all camper activity was spent in and around the campsite. It is only logical that communication efforts should be concentrated on these locations. A rule card, preferably plastic or metal, could be placed innocuously on such sites, and at restrooms and shower facilities.

Where an envelope system is used to collect fees, it could be modified to include a tear-off list of rules. This would require no additional work and costs would be minimal.

Burch (*1965*) and Hendee and Campbell (*1969*), studying the social aspects of camping, documented the significant role that social interaction plays in the recreation experience. During our study, we observed that campers willingly congregate for evening lecture programs. Such programs present opportunities for social interaction and entertainment. Since most evening lecture programs relate to the particular recreation environment, it should be possible to incorporate a discussion of rules. This would not only help to convey rules, but also would help to explain why such rules are needed.

Hendee and Campbell (*1969*) observed that the campfire functions as the center for social interaction, drawing people together. Congregating people around a campfire for informal discussions would provide an opportunity for



establishing communication and conveying rules.

Efforts to convey rules could be most productively directed toward adolescents, nonlocals, and tent-campers. Wagar (*1971*) found that people prefer to *hear* information rather than read it, particularly adolescents. One approach that would reach the entire group: a programmed audio-visual display. The display could be erected adjacent to a roadway pull-off located near the entrance to controlled access areas. Programmed displays would initially cost more than other communication methods, but would eliminate costly man-hours of personal contact, without significant recurring costs.

For areas with a central manned entrance, printed rule brochures could be used in addition to the previously mentioned audio display. The dual methods are suggested because a brochure's effectiveness depends on the manner in which it is distributed. Too often only the driver is exposed to the brochure.

Communication Means Should Be Designed and Applied in a Manner That Will Stimulate Camper Interest

The way in which the communicator conveys his message is of prime importance to communication of rules. Castro (*1972*) discussed the need for humanizing park signs. Signs could be more effective if any hostile or dogmatic tone were avoided. For example, "NO DOGS ALLOWED" could be changed to "SORRY—PETS NOT PERMITTED", or the sign "DO NOT ENTER" might be changed to "CLOSED".

Collectively, the above-mentioned means should help to increase knowledge of recreation-area rules, as well as improve understanding of why such rules are needed.

Care should be taken to create effective communication methods, and in directing them toward those segments of the recreating public most likely in need of the information.

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ACKNOWLEDGMENTS

The authors thank Dr. Donald Koten, associate professor, School of Environmental and Resources Management, State University of New York, College of Environmental Science and Forestry at Syracuse, New York, for his assistance in the design of this study. Credit is also due Ralph H. Freeman and Rodney G. Larson, forest supervisor and recreation staff officer, Allegheny National Forest, Warren, Pa., for their helpful suggestions and cooperation throughout the conduct of this research.

APPENDIX

Study Questionnaire

COVER SHEET

Interviewer: Fill in the following information:

Recreation area (check):
_____Kiasutha or _____Red Bridge

Camp Group number: _____

Date: _____

Time: _____

Questionnaire form (circle): A or B

Camp group makeup (enter numbers):
_____Children (Under 12)
_____Adolescents (12 to 17)
_____Adults (18+)

Camping equipment (check):
_____Tent
_____Tent-trailer
_____Trailer
_____Pickup camper
_____Mobile camper
_____Other (specify): _____

QUESTIONNAIRE

Q 1. Where do you live? (City and State): _____

Q 2. How many nights have you already camped here? _____(nights)

Q 3. How many separate camping trips have you made to the Allegheny National Forest last year and this year? _____ (number)

Q 4. How many camping trips have you made to other National Forests last year and this year? _____ (number)

Q 5. During this visit to the Allegheny National Forest, what major recreation activities have you engaged in? (Check all that apply):
_____Camping
_____Boating
_____Water skiing
_____Fishing
_____Swimming
_____Bicycling
_____Sight-seeing
_____Hiking

Q 6. Check the age group in which you fall:
_____Under 18
_____18 to 24
_____25 to 34
_____35 to 39
_____40 to 49
_____Over 50

Q 7. The following 10 questions are designed to determine your understanding of the recreation rules that apply to use of this recreation area. We are trying to get a measure of the effectiveness of efforts used to convey rules to people who use the area. For each item, simply check "true" if you feel the statement is correct, "false" if you feel the statement is incorrect, and "don't know" if you are not sure whether the statement is correct or incorrect. PLEASE DO NOT GUESS at your answers. Guessing will invalidate the objective of this study. We are not testing <u>you</u>, but are testing the effectiveness of current methods used to convey rules.

a. If you have paid in advance for your site, you may leave your camping equipment unattended for more than 24 hours?
_____True _____False _____Don't know

b. At all times within camp and picnic grounds, dogs, cats, and any other animals must be confined on a leash?
_____True _____False _____Don't know

c. Small pack tents may be pitched for evening use in picnic areas after 8:00 p.m.
_____True _____False _____Don't know

d. Even though a limb on a tree appears to be dead, it may not be used as firewood.
_____True _____False _____Don't know

e. Small motorized bikes may not be operated on roadways within camp areas during daylight hours.
_____True _____False _____Don't know

f. Because food wastes are decomposable and serve as food source for many forest animals, they may be deposited on the ground in small quantities.
_____True _____False _____Don't know

g. Clothing or articles of household use may not be washed at hydrants in recreation sites.
_____True _____False _____Don't know

h. Leashed dogs and cats are allowed at developed swimming beaches.
_____True _____False _____Don't know

i. A camper may set up and leave his camping unit unoccupied the first night if the site is attended the next morning.
_____True _____False _____Don't know

j. Besides hikers, only bicycles are allowed on trails within developed recreation areas.
_____True _____False _____Don't know

Q 8. Have you seen a National Forest recreation rule brochure?
_____Yes (go to question 9)
_____No (go to question 10)
_____Don't know (go to question 11)

Q 9. Where did you see this brochure? (Check all that apply):
_____At the public information center
_____At your recreation site
_____At another National Forest
_____At stores or restaurants within or near the Allegheny National Forest
_____Other places (please list): _____

Q 10. Did you notice posted signs explaining rules and regulations as you entered this camping area or as you moved around in the area?
_____Yes (go to question 11)
_____No
_____Don't recall

Q 11. Did you read any of these posted signs?
_____Yes
_____No
_____Don't recall

THANK YOU for taking the time to fill out this questionnaire. If you have any questions about this area, the interviewer would be most happy to answer them as best he can. He also has a copy of the National Forest rule brochure that contains the correct answers to the questions asked earlier.

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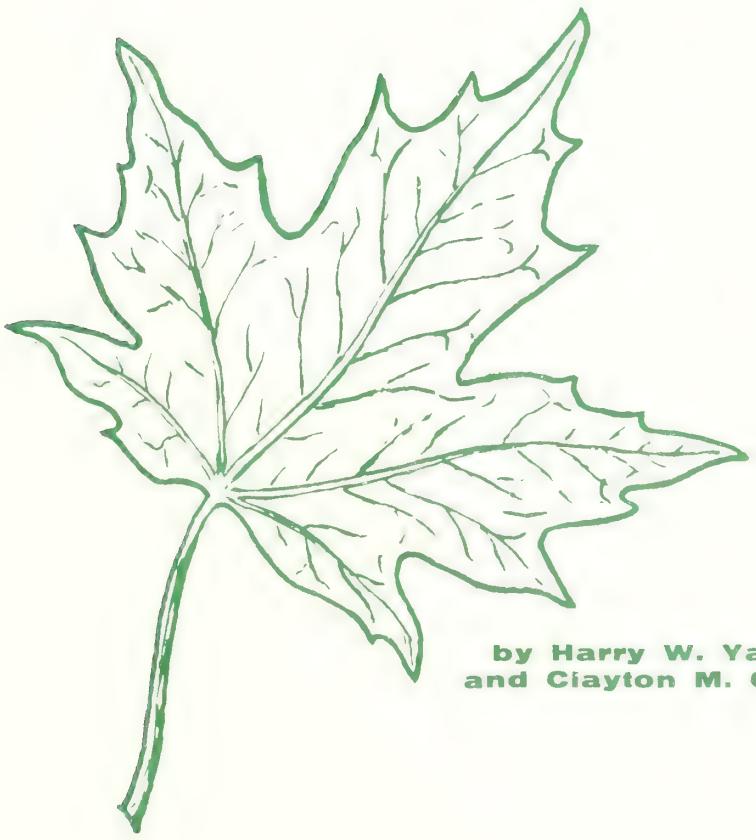
Storage Requirements for SUGAR MAPLE Seeds



by Harry W. Yawney
and Clayton M. Carl, Jr.

USDA FOREST SERVICE RESEARCH PAPER NE-298
1974

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MANUSCRIPT RECEIVED FOR PUBLICATION 15 MARCH 1974

Storage Requirements for SUGAR MAPLE Seeds

ABSTRACT

Sugar maple seeds, collected from three trees in northern Vermont, were stored at four temperatures (18, 7, 2, and −10°C) in combination with four seed moisture contents (35, 25, 17, and 10 percent). Seed moisture content and storage temperature significantly affected keeping ability, and these factors were highly interrelated. Seeds from all trees kept best at the lowest temperature and lowest moisture content tested.

SUGAR MAPLE (*Acer saccharum* Marsh.) is one of our most valuable hardwood trees. Because of its economic importance to both the wood-using and maple-syrup industries, sugar maple has become the object of intensive seeding and planting research by the Northeastern Forest Experiment Station laboratory at Burlington, Vermont. One phase of this research, which is reported in this paper, deals with seed storage. Some early results of this research were reported by Yawney (*1968*).

Sugar maple produces good seed crops at intervals varying from 2 to 7 years (*USDA 1948; Harlow and Harrar 1958*). Because of irregularity in seed production, we investigated the requirements for long-term storage to provide an adequate seed supply during poor crop years.

The purpose of determining the proper storage environment for any seed is to maintain it at the lowest possible level of metabolic activity without impairing its viability. In general, the critical factors for maintaining seeds in storage are temperature and seed moisture content (*Crocker and Barton 1957*).

The storage requirements for seed of many of our important tree species have been adequately defined, but the seed of sugar maple has received little attention. Information in the *Woody Plant Seed Manual* (*USDA 1948*) indicates only that sugar maple seeds will remain viable for at least a year in either open or sealed containers when stored at 36° to 40°F. However, suitable moisture content is not indicated. Stanley and Butler (*1961*) reported that sugar maple seed can be dried to a moisture content of about 5 percent without lowering germination, but gave no further recommendations.

In view of this limited information, we studied the effects of different combinations

of storage temperatures and seed moisture contents on the keeping ability of sugar maple seed.

METHODS AND MATERIALS

We collected sugar maple seeds from three mature trees in northern Vermont during 2 weeks in late September and early October 1962. The percentages of the samaras containing seeds in the three collections were 68, 55, and 72. The empty samaras were not removed from the collections.

The experiment was designed to test the effects of four seed moisture contents—35, 25, 17, and 10 percent (dry-weight basis)—in all combinations with four temperatures—18, 7, 2, and −10°C—for a total of 16 storage conditions.

Each tree collection (seedlot) was kept separate. We were able to air-dry the seedlots slowly to 17 percent moisture content in an unheated building. Drying to 10 percent moisture content required transferring the seedlots to a heated room. The length of time required to dry the seeds varied from 30 to 60 days, depending upon the initial moisture content and the final moisture content specified for storage.

Each sample, consisting of 150 samaras, was stored in a 6-oz. glass jar and sealed with a rubber-lined metal screw cap (fig. 1) to insure moisture content stability. Facilities for maintaining the prescribed temperatures included kitchen-type refrigerators for 18° and 7°C, a walk-in cooler for 2°C, and a chest-type freezer for −10°C. (The assistance given by the Champlain Valley Fruit Co., Burlington, Vermont, by providing space for their 2°C facility during the study is gratefully acknowledged.)

Because of the unknown effects of storage in sealed containers, we stored additional samples from each collection in each temperature facility in open jars. In these samples no attempt was made to maintain the seed at fixed moisture contents. At the start of the experiment these samples had an initial moisture content of about 22 percent.

Seed moisture content in each storage facility was monitored throughout the course of the study.

We used germination as the criterion of

Figure 1.—A storage sample consisting of 150 sugar maple samaras in a 6-oz. jar.

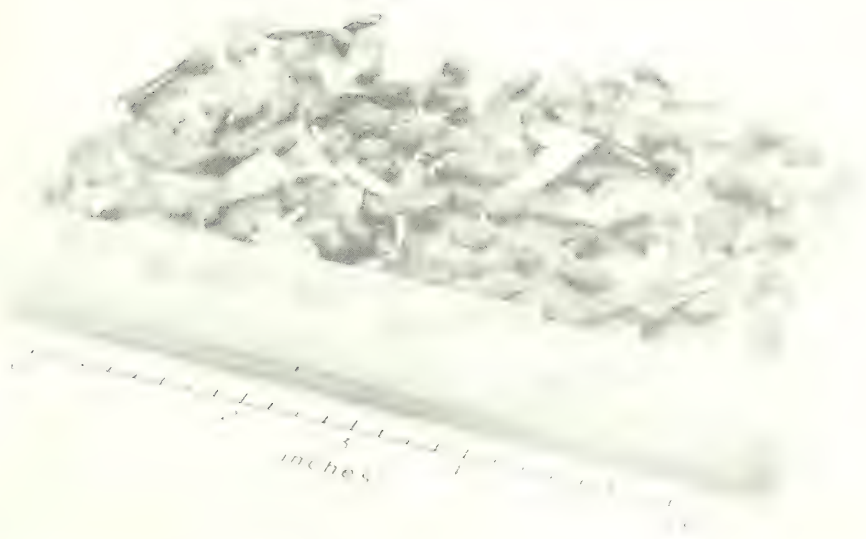

Figure 2.—Sugar maple seeds germinating in a test sample.

seed viability. We considered a seed germinated as soon as its radicle became visible (fig. 2). Germination tests were made before storage, at the end of 6 months, and then annually for 4 additional years. Viability was determined on the basis of three 150-samara samples from each seedlot for each storage condition. Thus, at the end of each storage period, we tested 144 samples from sealed containers and 36 samples from open containers.

Each sample was germinated separately, following the procedure described for sugar maple seeds by Carl and Yawney (*1966*). We soaked the samples in tap water for 24 hours and then placed them on moist germination paper in plastic boxes. We kept them in darkness at 2 to 4°C in a walk-in cooler for 90 days followed by 2 weeks in a greenhouse at about 23°C. At the conclusion of each germination test, we opened the remaining samaras to determine the number of seeds that failed to germinate. The ungerminated seeds plus the germinants were used to calculate the percentages of germination.

The sealed and open containers represented two experiments; therefore, the data were analyzed separately. The design of the experiment for the sealed-container series was that of a 3 x 4 x 4 x 5 factorial (3 seedlots, 4 moisture contents, 4 temperatures, and 5 storage periods), and for the open containers a 3 x 4 x 5 factorial (3 seedlots, 4 temperatures, and 5 storage periods). Viability was recorded in percentages, which were transformed (arc-sin) for use in the analysis.

RESULTS AND ANALYSIS

The germination tests before storage indicated that viability was 97 percent for tree 1, 98 percent for tree 2, and 99 percent for tree 3. Results of our germination tests made at

the end of 6, 18, 30, 42, and 54 months are summarized for the sealed containers in table 1 and for the open containers in table 2.

Sealed-container experiment.—During the study, the deteriorating effects of unfavorable storage conditions on sugar maple seed followed a distinct pattern that was similar for all three seedlots. Samples stored at the highest temperatures and highest moisture contents were the first to be affected.

At the end of 6 months, complete loss of viability was recorded in all samples stored at 18°C and 35 percent moisture content. As storage continued, samples previously unaffected showed signs of deterioration as loss of viability progressed gradually into the lower treatment levels with each succeeding year.

When the study was completed, we found that only 4 out of the 16 storage conditions tested maintained the seed with little or no loss in viability. These conditions were −10°C in combination with 17 percent moisture content; and 7, 2, and −10°C in combination with 10 percent moisture content.

Our analysis of the data in table 1 verified the obvious significance of temperature, seed moisture, and storage period. Differences between seedlots were also found to be highly significant. Moreover, the analysis revealed that not only were all these factors highly significant, but that all interactions between them were as well.

Open container experiment.—Losses in viability in samples stored in the open con-

Table 1.—*Effects of seedlot, moisture content, temperature, and time on the viability of sugar maple seed stored in sealed containers, in percent*

Seed moisture content (percent)	Storage temperature (°C)	(Seedlot 1:) months in storage—					(Seedlot 2:) months in storage—					(Seedlot 3:) months in storage—				
		6	18	30	42	54	6	18	30	42	54	6	18	30	42	54
35	18	0[1]	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	7	83	0	2	0	0	86	0	2	0	0	99	0	1	0	0
	2	95[2]	8	1	0	0	94	19	0	0	0	95	4	0	0	0
	−10	95	93	87	1	0	94	88	93	8	2	95	99	86	1	0
25	18	44	0	2	0	0	0	0	0	0	0	2	0	0	0	0
	7	95	65	3	0	0	96	23	0	0	0	100	51	0	0	0
	2	95	85	50	7	0	97	89	9	0	0	100	99	69	1	14
	−10	97	95	96	46	7	96	98	98	3	9	93	99	98	3	14
17	18	62	0	0	0	0	15	1	0	0	0	40	0	1	0	0
	7	95	86	0	0	0	96	62	0	0	0	100	94	5	0	0
	2	97	93	82	58	60	99	94	73	4	0	100	98	98	83	14
	10	97	96	93	92	86	97	98	97	92	95	99	99	100	97	98
10	18	90	55	1	1	0	94	68	0	0	0	100	95	9	0	0
	7	89	91	91	93	85	93	95	95	92	92	100	100	100	98	96
	2	93	93	89	91	94	97	95	96	93	96	100	100	99	100	99
	10	95	95	97	89	94	96	96	96	97	94	99	98	99	99	99

[1]Viability percentages are averages of 3 samples.
[2]Percentages within the shaded area are not significantly different from each other.

Table 2.—*Effects of seedlot, temperature, and time on the viability of sugar maple seed stored in open containers, in percent*

Storage temperature (°C)	(Seedlot 1:) months in storage—					(Seedlot 2:) months in storage—					(Seedlot 3:) months in storage—				
	6	18	30	42	54	6	18	30	42	54	6	18	30	42	54
18	67[1]	0	2	0	0	93	0	1	0	0	98	2	1	0	0
7	97[2]	58	41	28	10	98	62	52	50	11	100	95	87	80	50
2	94	76	19	0	0	96	81	3	0	0	100	99	40	1	0
−10	96	98	97	71	63	98	98	98	96	90	99	100	100	98	98

[1]Viability percentages are averages of 3 samples.
[2]Percentages within the shaded areas are not significantly different from each other.

Table 3.—*Moisture contents of samples stored in open containers in each temperature storage facility at different periods during the study*

Storage temperature (°C)	Approximate relative humidity	(Seedlot 1:) months in storage—						(Seedlot 2:) months in storage—						(Seedlot 3:) months in storage—					
		Initial	6	18	30	42	54	Initial	6	18	30	42	54	Initial	6	18	30	42	54
	Percent		Percent						Percent						Percent				
18	26	24[1]	6	6	6	—	—	19	9	7	6	—	—	23	9	8	8	—	—
7	60	24	18	12	11	7	8	19	17	10	10	7	7	23	17	11	11	8	8
2	84	24	23	18	18	20	17	19	22	16	16	17	14	23	22	17	17	22	19
−10	81	24	21	18	21	21	18	19	15	15	16	19	18	23	17	16	17	17	16

[1]Moisture contents are averages of 10 samples.

tainers (table 2) generally reflected the effects of storage condition found in the sealed-container series. Again, 18°C proved to be the most detrimental to seed viability, while maximum viability was maintained at −10°C. The relative humidities and the seed moisture contents in each storage unit are given in table 3.

An analysis of variance showed, as with the sealed samples, that seedlot, storage temperature, storage period and all their interactions were also highly significant.

DISCUSSION

This study clearly demonstrated that long-term storage of sugar maple seed is possible. The length of time that seeds remain viable is influenced by storage temperature, seed moisture content, and seedlot, and that all of these factors interact with each other in their effects.

In view of the total interaction, very little can be said about the individual contribution of each variable, but it appears that moisture content is probably the most important. The inferences that can be drawn from the data are as follows: (1) there were differences in storability between seedlots; (2) both storage temperature and seed moisture content influence seed viability over extended periods, and that these factors interact in their effects; (3) the effect of the interaction of temperature and moisture content changes in degree with seed from different trees; and (4) the degree of these changes is not necessarily consistent from one storage period to the next.

Differences between the keeping quality of the three seedlots were probably due to the stage of maturation of the seed at the time of collection. We noted that samaras from tree 1 were bright green in color, giving a fresh appearance; they were firmly attached to the peduncles and did not separate easily. In contrast, samaras from tree 3 were yellow in color, with orange and brown mottling, and were easily shed from the tree. Seeds in lot 2 appeared to be intermediate in their development.

The data suggest that, had the study continued for several more years, seedlot 3 would have kept in storage significantly longer than lot 2, and lot 2 would have kept longer than lot 1. The relative strength of each seedlot, or the differences in their keeping quality, can be assessed by comparing the patterns of the shaded area between seedlots in tables 1 and 2.

Reporting on the maturation of sugar maple seed, Carl and Snow (*1972*) found that considerable variation exists among trees. They reported that germination potential develops rapidly, requiring as little as 2 weeks to go from 0 to 95 percent, and that near maximum potential is reached about 4 to 5 weeks in advance of seedfall. Their findings and the results from our study suggest that, although the seeds may be structurally complete and have high germination percentages, they may not be completely tree ripened.

Barnett and McLemore (*1970*) reported that longleaf pine seeds collected from a given tree 1 year may store well, while seeds collected from the same tree in another year may store poorly. They speculated that, if the seeds have not reached some critical stage of maturity, they will fail rapidly in storage.

To insure a high germination potential and to insure good retention of viability during storage, we recommend that sugar maple seeds not be collected until the samaras have lost their bright green color.

A comparison of the data in tables 1 and 2 suggests that seed in sealed containers retained their viability better than those in open containers. This may be due in part to a reduction of the oxygen supply in the sealed containers, which would favor retention of viability (*Crocker and Barton 1957*).

In this study, however, we attributed losses in germination capacity of the open stored seed largely to the high initial moisture content (around 22 percent) when the study began and the high relative humidities present in the storage facilities. In those storage units that permitted the adjustment of the seed moisture content downward, storage life of the samples was significantly lengthened. For example, seedlot 3 in open containers had an initial moisture content of 23 percent. When stored at 7°C, it was gradually reduced to about 10 percent, and at the end of 4½ years was still 50 percent viable. In contrast, seedlot 3, held at 25 percent moisture content in sealed containers at 7°C, failed to germinate after 2½ years.

We conclude that results equally as good can be achieved with either sealed or open containers, provided a low temperature and a low seed moisture content are maintained. As a practical extension of this study, we have practiced storing sugar maple seeds, which have been dried to 10 percent moisture content or less, in lots of 10,000 or more in closed plastic containers in ordinary kitchen freezers with excellent results.

SUMMARY AND CONCLUSIONS

Sugar maple seeds collected in northern Vermont were successfully stored for 4½ years—the duration of this study. We found the conditions necessary for long-term storage to be a combination of a low temperature and a low seed moisture content. When the study was completed, germination capacity remained at about prestorage levels for those seed stored with 17 percent moisture content at −10°C, and with 10 percent moisture content at 7, 2, and −10°C.

On the basis of the trends indicated by our data, we believe that the seeds could have been stored for a considerably longer period than that covered by this study. The most favorable conditions for continued storage appeared to be with 10 percent moisture content and at −10°C.

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Forest Vegetation Related to Elevation in The White Mountains of New Hampshire

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by William B. Leak
and Raymond E. Graber

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MANUSCRIPT RECEIVED FOR PUBLICATION 8 FEBRUARY 1971

Forest Vegetation Related to Elevation in The White Mountains of New Hampshire

ABSTRACT

Maximum tree size and species composition are related to elevation on Mount Washington (disturbed by logging) and Mount Whiteface (uncut) in the White Mountains of New Hampshire. Species migrational trends and differences between the two mountains in species elevational limits indicate that both hardwoods and softwoods will move to higher elevations in areas where cutting and heavy disturbance are eliminated.

IN THE MOUNTAINOUS areas of New England, elevation above sea level is one of the most important factors affecting the species composition and structure of forest vegetation. Because these forest characteristics relate closely to resource values and management possibilities, there is need for specific information about the influence of elevation.

Much of the past research on mountain ecology in New England has dealt with the alpine zone above timberline (*Bliss 1963 and 1966, Harries 1961, Griggs 1946*). Information about elevational relationships is available for the Adirondacks (*Holway and Scott 1969*) and the Green Mountains of Vermont (*Siccama 1968*). However, outside of the detailed vegetational work on the Hubbard Brook watersheds (*Bormann et al. 1970*), little specific information is available for the White Mountain range, which differs somewhat from other New England mountain systems in topography, geology, and past use.

AREAS AND METHODS

Our research dealt with two mountains in New Hampshire: Mount Washington, which is 1,917 meters (6,288 feet) high, and Mount Whiteface, 1,215 meters (3,985 feet) high. Mount Washington is a heavily used recreational area, whose lower slopes up to about 914 meters (3,000 feet) were irregularly logged up until the late 1800s. The study area on Mount Whiteface, in the Bowl Research Natural Area, has never been logged.

In the summer of 1971, a transect was laid out on the southeastern slope of Mount Washington, beginning at an elevation of 632 meters (2,073 feet) near the Appalachian Mountain Club's Pinkham Notch base camp and ending

at 1,373 meters (4,505 feet) at the base of Nelson's Crag. At every 10-meter rise in elevation, measured with an aneroid barometer, a series of nested plots was set out.

On the main plot, which was 3 x 20 meters, laid out along the contour, the diameter above root swell was measured on all trees of at least 50 millimeters diameter. Ages of the largest and smallest stems (including those less than 50 mm) were determined by boring, sectioning, or counting terminal bud scars. On a 3 x 3-meter subplot, diameter was measured on all stems that were between 1.372 meters tall (4.5 feet) and 50 mm diameter.

Smaller vegetation was measured on a 1 m^2 circular subplot. Diameters were measured just above root swell (right at the point of curvature for the root swell on the uphill side of the tree) because this point can be identified on all sizes of trees and it is approximately the point used in making increment borings. Dbh proves useless on young trees and on stunted trees near timberline.

During the summer of 1972, a compass line was run up the northeast side of Mount Whiteface, beginning at an elevation of 610 meters (2,000 feet) at the Wonalancet River in the base of the Bowl and ending at 1,201 meters (3,940 feet) near the mountain top. At every 50-foot (15.24 m) rise in elevation, basal areas by species were accumulated with a 10-factor prism. The largest tree per species in the prism plot was measured for diameter just above the root swell and aged with an increment borer. The smallest stems per species on the prism plot or a 1 x 10-meter subplot also were measured and aged.

On both transects, elevations were double-checked at several points, and the errors were distributed. These corrected plot elevations were used in analyzing the data.

RESULTS AND DISCUSSION

Maximum Tree Diameter

Maximum tree diameters commonly ran considerably larger on Mount Whiteface than on Mount Washington except at elevations above 900 meters (table 1). This pattern probably resulted from the logging activity on Mount Washington before the turn of the century. For the typical northern hardwoods—beech, yellow birch, and sugar maple—no substantial diminution in tree size was evident on Mount Whiteface up to 900 meters. For the spruce-fir components—red spruce, balsam-fir, and paper birch—tree size remains large up to 1,100 meters on Mount Whiteface and 1,200 meters on Mount Washington.

For those who use diameter measurements at breast height, dbh in mm can be estimated from diameter above root swell by:

Hardwoods: Dbh (mm) = −11.68 + 96 (dia. mm, root swell)
$R^2 = .997$
$S_{yx} = 10.04$

Softwoods: Dbh (mm) = −17.80 + .95 (dia. mm, root swell)
$R^2 = .996$
$S_{yx} = 10.43$

Basal Area and Species Composition

On both Mount Washington and Mount Whiteface, basal areas per acre increased moderately with elevation as the proportion of softwoods increased. Then basal area seemed to decline at 1,100 meters on Mount Whiteface and at 1,300 meters on Mount Washington. Percent species composition differed somewhat between the two areas, partly because of the differences in past land use.

In general, Mount Washington has a wider range of species than the late-successional stands on Mount Whiteface (table 2). However, on both areas the typical northern hardwoods are most abundant in the 600 to 700 meter elevation classes. Red spruce appears in greatest abundance in the 800 to 1,000 meter elevation classes. Balsam-fir first becomes an important component in the 800-meter class and continues to increase in relative abundance with higher elevation. On Mount Washington, paper birch is abundant from the 700- through 1,100-meter class, while on Mount Whiteface it is evident mainly in the 1,000 to 1,100 meter classes.

Species' Elevational Ranges

Based on the occurrence of stems more than 1 year old, elevational ranges of species were

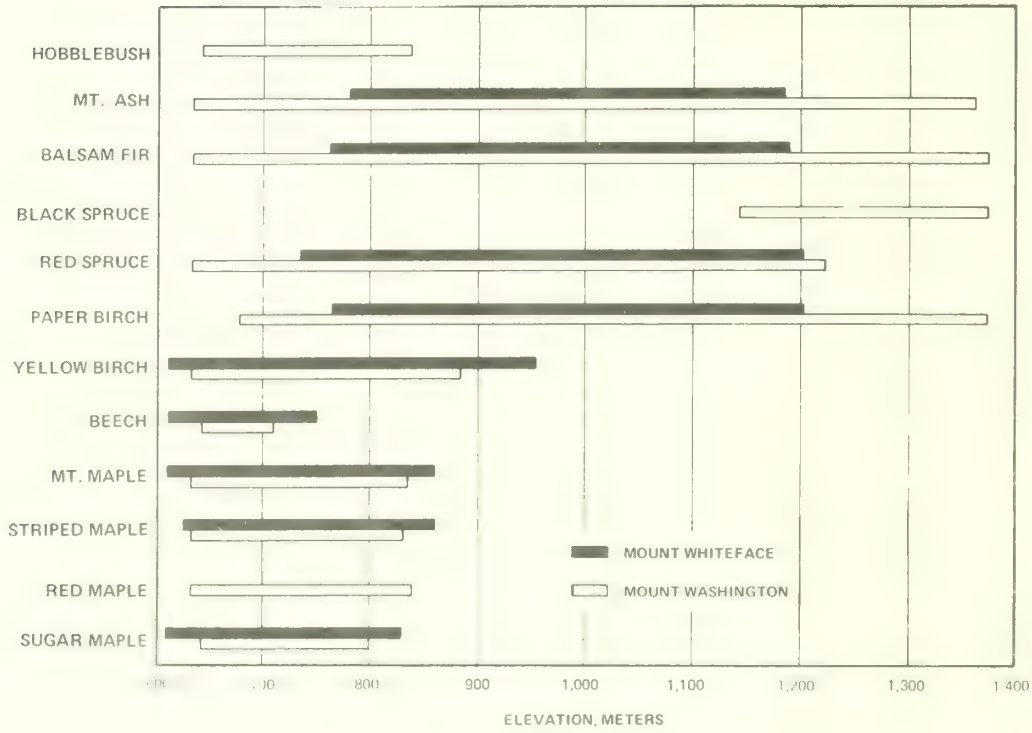
Table 1.—*Maximum tree diameters, by species and 100-meter elevation classes (600 to 699, etc.)*
[In mm, above root swell]

Elevation class (meters)	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	Mt. maple	Striped maple	Mt. ash	Aspen	Red spruce	Balsam fir	Eastern hemlock	Black spruce
MOUNT WHITEFACE													
600	567	806	779	—	—	—	—	—	—	—	—	—	—
700	444	724	632	—	435	97	195	190	—	710	119	—	—
800	—	684	518	—	404	—	165	230	—	686	309	—	—
900	—	317	—	—	456	—	—	—	—	645	248	—	—
1,000	—	—	—	—	480	—	—	183	—	597	274	—	—
1,100	—	—	—	—	270	—	—	179	—	344	285	—	—
1,200	—	—	—	—	—	—	—	—	—	147	160	—	—
MOUNT WASHINGTON													
600	219	628	179	370	301	66	126	—	—	—	90	583	—
700	73	371	353	—	284	—	137	—	352	59	99	—	—
800	—	354	—	—	231	—	—	278	—	306	352	—	—
900	—	—	—	—	337	—	—	221	—	530	318	—	—
1,000	—	—	—	—	540	—	—	—	—	684	544	—	—
1,100	—	—	—	—	460	—	—	—	—	556	337	—	227
1,200	—	—	—	—	291	—	—	—	—	281	306	—	254
1,300	—	—	—	—	173	—	—	81	—	—	321	—	149

Table 2.—*Average species composition, by species and 100-meter elevation classes*
[In percent of total basal area]

Elevation class (meters)	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	Mt. maple	Striped maple	Mt. ash	Aspen	Red spruce	Balsam fir	Eastern hemlock	Black spruce
MOUNT WHITEFACE													
600	29	25	46	—	—	—	—	—	—	—	—	—	—
700	28	32	15	—	6	—	2	5	—	10	2	—	—
800	—	18	4	—	8	—	4	2	—	42	22	—	—
900	—	2	—	—	4	—	—	—	—	61	33	—	—
1,000	—	—	—	—	15	—	—	2	—	37	46	—	—
1,100	—	—	—	—	38	—	—	3	—	14	45	—	—
1,200	—	—	—	—	—	—	—	—	—	24	76	—	—
MOUNT WASHINGTON													
600	2	60	4	17	4	1	1	—	—	—	1	10	—
700	—	45	12	—	32	—	1	—	7	2	1	—	—
800	—	17	—	—	12	—	—	3	—	19	49	—	—
900	—	—	—	—	14	—	—	1	—	38	47	—	—
1,000	—	—	—	—	15	—	—	—	—	37	48	—	—
1,100	—	—	—	—	13	—	—	—	—	16	68	—	3
1,200	—	—	—	—	5	—	—	—	—	3	90	—	2
1,300	—	—	—	—	3	—	—	—	—	—	89	—	8

Figure 1.—Elevational ranges of woody species on Mount Whiteface and Mount Washington, based on occurrence of stems over 1 year old. Transects began at 610 and 632 meters above sea level and ended at 1,201 and 1,373 meters, respectively.



graphed for each area (fig. 1). Occasional outliers were ignored. Northern hardwoods generally occur below 850 meters, although yellow birch is found up to 950 meters. The softwoods (and paper birch) are found throughout a much broader range although, as noted earlier, they become predominant above 800 meters.

Note that the elevational ranges of the hardwoods are consistently narrower in the disturbed Mount Washington stands than in the uncut Mount Whiteface stands. The opposite is true with softwoods: softwood (and paper birch) ranges are narrower on Mount Whiteface than on Mount Washington.

It seems likely that, when cutting is eliminated, northern hardwood ranges will expand to their upper limit—850 to 950 meters—while softwood ranges will retreat. The end result would be a general reduction in lower-altitude softwoods and a fairly strict line of demarcation between the northern hardwood and spruce-fir associations. Paper birch would remain as a permanent resident in the spruce-fir association.

The same conclusions can be made from preliminary information about the detection of species' migration. When maximum and minimum ages are plotted over elevation (or distance), it becomes possible to detect advancing, stable, or retreating species fronts. The data from Mount Washington, already published, indicated that the hardwoods generally were advancing uphill, while paper birch and spruce-fir were retreating. In contrast, the more recent data from Whiteface indicate that the northern hardwoods such as beech (fig. 2) and sugar maple have attained almost perfectly stable uphill fronts. Yellow birch (fig. 3) still seems to be advancing uphill, while the lower end of its elevational range is retreating uphill drastically (although the shape of the lower front is not well defined by the data). The softwoods and paper birch (fig. 4) seem to be retreating only sporadically and slowly uphill.

Figure 2.—Maximum and minimum age for beech over elevation, showing approximate shape of migrational fronts. Mount Whiteface.

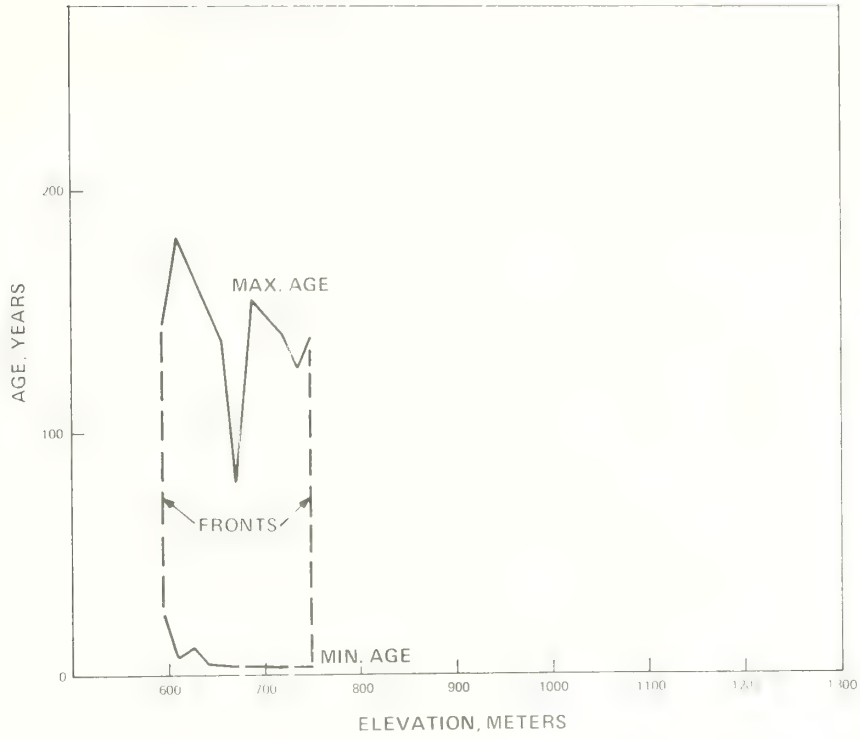
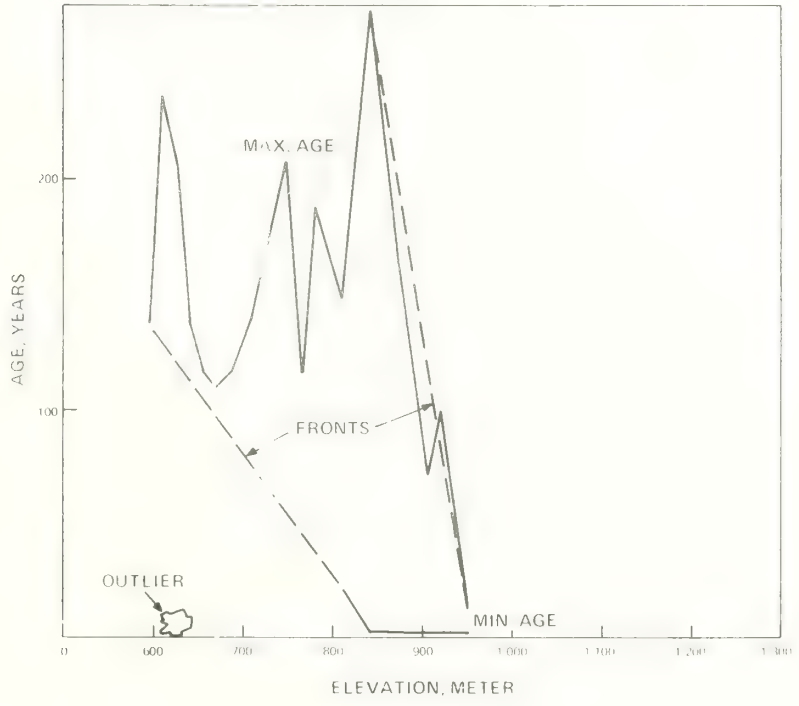


Figure 3.—Maximum and minimum age for yellow birch over elevation, showing approximate shape of migrational fronts. Mount Whiteface.



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Weight and Volume Variation in Truckloads of Logs Hauled in the Central Appalachians

by Floyd G. Timson

MAR 26 1975

USDA FOREST SERVICE RESEARCH PAPER NE-300
1974

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MANUSCRIPT RECEIVED FOR PUBLICATION 8 FEBRUARY 1974

COVER PHOTO

A typical truckload of logs arriving at the mill. Measurements of this load were: Weight—30,620 lbs.; volume, Doyle—2,075 fbm; volume, International—2,860 fbm; cross sectional load area—67.9 ft²; percentage of space utilized—51.4

Abstract

Variation in volume and weight was found among loaded log trucks even when such factors as truck type, logging job, and driver influence were eliminated. A load range of 10,000 pounds or 1,000 board feet was commonplace for the same truck, driver, and cutting site. Differences in log size, shape, weight, and species caused a major share of this variation. Yet, improvements such as higher stakes and proper log selection could increase average load size to legal load capacity. If the underloaded trucks in this study had been brought up to legal weight allowances, delivery costs would have been reduced by $5.56 per MBF.

Weight and Volume Variation in Truckloads of Logs Hauled in the Central Appalachians

SAWLOG TRANSPORT is the major harvesting cost element in the Appalachian Mountain region. An important characteristic of this function, for a given timber source and destination, is that the truckload cost remains relatively constant over a wide range of load sizes. Therefore, maximizing load size helps minimize unit delivery cost.

Both logging contractors and company foresters need specific information on payloads hauled to manage their businesses more effectively. Design engineers could also use this data to help them plan better truck body styles.

Prior to this study, very little information on load variation was available. Most sawtimber operators know that there are differences among loads of logs but they accept this dissimilarity as a natural phenomenon. For this reason, there has been little interest in pinpointing reasons for load variation or assessing the effect of these variations on hauling costs.

We had three objectives in conducting this study: (1) to present to researchers and timber operators data on truckload volume and weight common to harvesting operations in mountainous terrain of Appalachia, (2) to observe, measure, and offer empirical explanations for variations in truckload quantities, and (3) to make recommendations for increasing hauling efficiency within the limitations of legal weight and truck engineering.

STUDY METHODS

The study was conducted at seven mills in the central Appalachian Mountain region.[1] At each of these mills, we recorded individual log weight and volume on loaded trucks arriving at the log yard. Weight was recorded in pounds and volume was recorded in cubic feet and in board feet by the Doyle and International log rules. No restrictions were placed on the origin of the loads or the size and model of the truck. When the field crew finished collecting data from one truckload, they would measure the next available load regardless of truck style, size, model, or load origin.

At three of the seven mills, we took a subsample to provide additional information on truckload variation. Each subsample represented a specific cutting site, truck type, and driver. Thus we were able to eliminate variables such as truck type, hauling distance, topography, legal restrictions, and driver. Since

[1] Includes the mountain regions of West Virginia, southwest Virginia, and western Maryland.

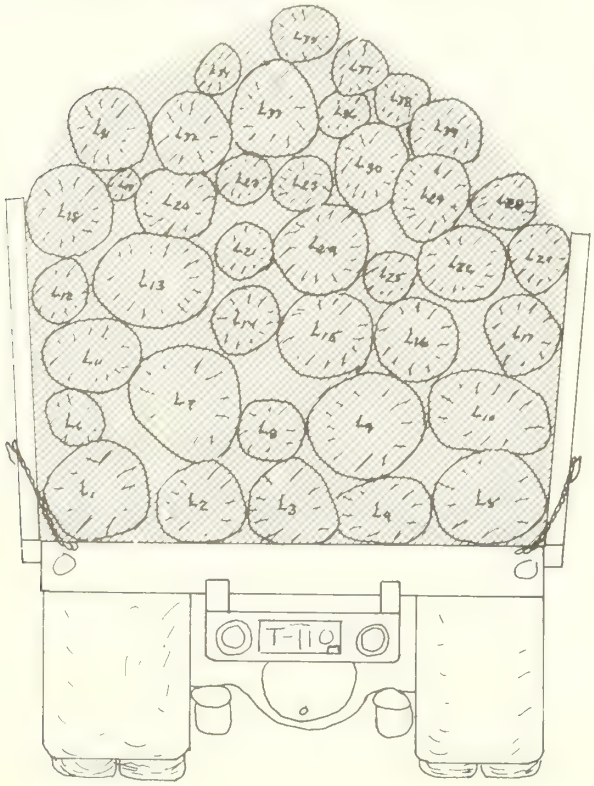
these subsamples were taken over a period of only 2 weeks, we reduced the influence of other variables such as change in road condition, climatic effects, and combinations of species and log sizes.

Using these three subsamples, each tandem-axle truck was identified so that loads could be recorded by cutting site, vehicle capacity and body configuration, and driver. Additional data recorded for each log consisted of diameter at both ends, length, species, weight, sweep, and which end of the log was at the rear end of the truck.

Photographs were taken of the rear of each loaded truck. Each photograph was enlarged to a designated scale and the area occupied by the load as viewed from the rear of the truck was measured (fig. 1). This area, including the logs and the air spaces between them, was called the "cross sectional area." Dispace occupied by all the logs on the load was called the "log end cross sectional area." Dividing the log end cross sectional area by the cross sectional load area gives the percentage of load space utilized by the logs alone.

The percent of load space utilized, while affected by some log irregularities, provided a measure of how well the loadermen and drivers used the area in which they put the logs that were available for loading. Log irregularities, which include conditions such as surface roughness, out-of-roundness, sweep, and crook, can influence how well a load fits together. But careful loading can help minimize these influences.

Figure 1.—Measurements for describing construction of log loads. Cross sectional load area = area of shaded portion in square feet. Log end cross sectional area = square feet end area L_1 + square feet end area L_2 + square feet end area L_{3+} ––– square feet end area L_n (L_{39} in above load). Percent of space utilized (by logs alone) = Log end cross sectional area/cross sectional load area.



LOAD VARIATION

At each of the seven mills, we observed substantial differences in volume and weight among the loads of logs sampled. Considerable variations still existed even after the loads were stratified by cutting site, truck type and size, and driver.

The loads of logs delivered to the seven mills by tandem-axle trucks ranged from 17,710 to 37,520 pounds. Load volumes ranged from 1,199 to 3,759 board feet by the Doyle rule and 1,655 to 4,030 board feet by the International rule, and from 342 to 689 cubic feet (table 1).

Table 1.—Variation in truckloads of logs delivered to representative mills in the south central Appalachian Mountain region

Item	Measurements			
	Weight	Volume Doyle	Volume Int. ¼	Volume
	Lb	*Fbm*	*Fbm*	*Ft*³
	TANDEM AXLE			
Max. load	37,520	3,759	4,030	689
Min. load	17,710	1,199	1,655	342
Ave. load	27,593	2,365	2,843	508
Std. dev.	3,741.0	461.2	445.7	70.6
	SINGLE AXLE			
Max. load	26,570	2,396	2,870	507.5
Min. load	13,500	1,034	1,315	228
Ave. load	18,649	1,607	1,923	328
Std. dev.	2,667.8	271.7	289.8	48.1

Figure 2.—Distribution of truckload weights of logs from selected cutting locations in the central Appalachians.

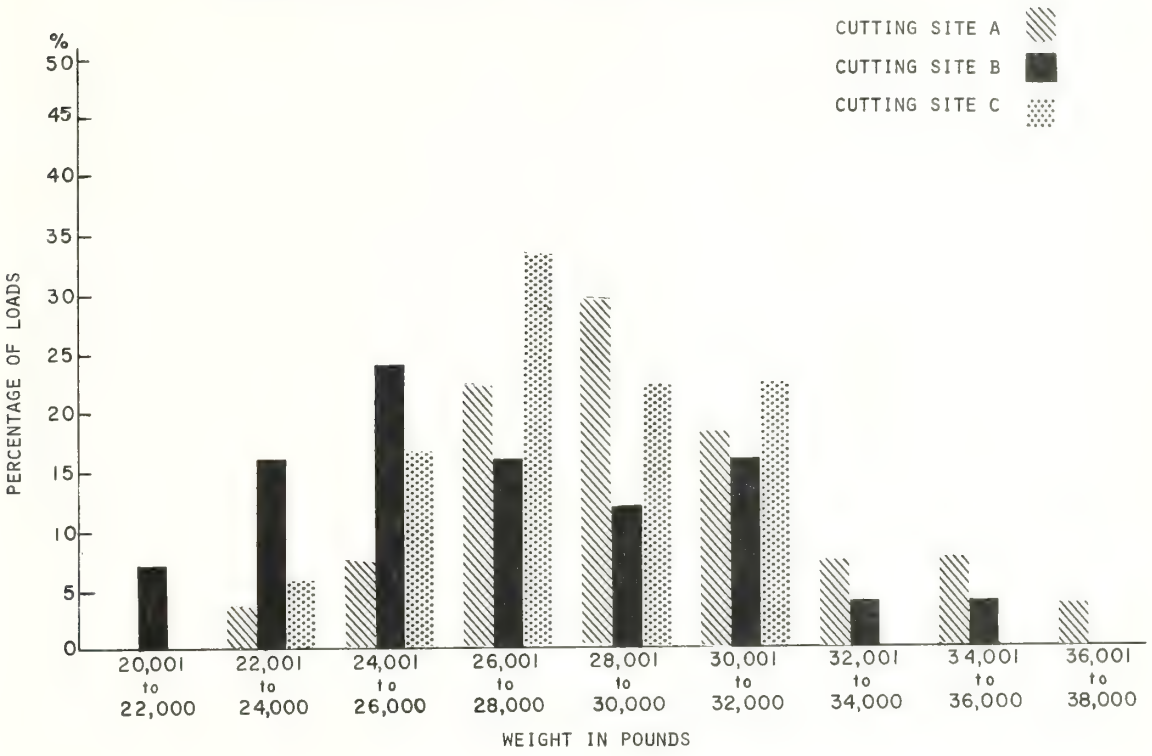


Figure 3.—Distribution of truckload volumes (board feet, Doyle) of logs from selected cutting locations in the central Appalachians.

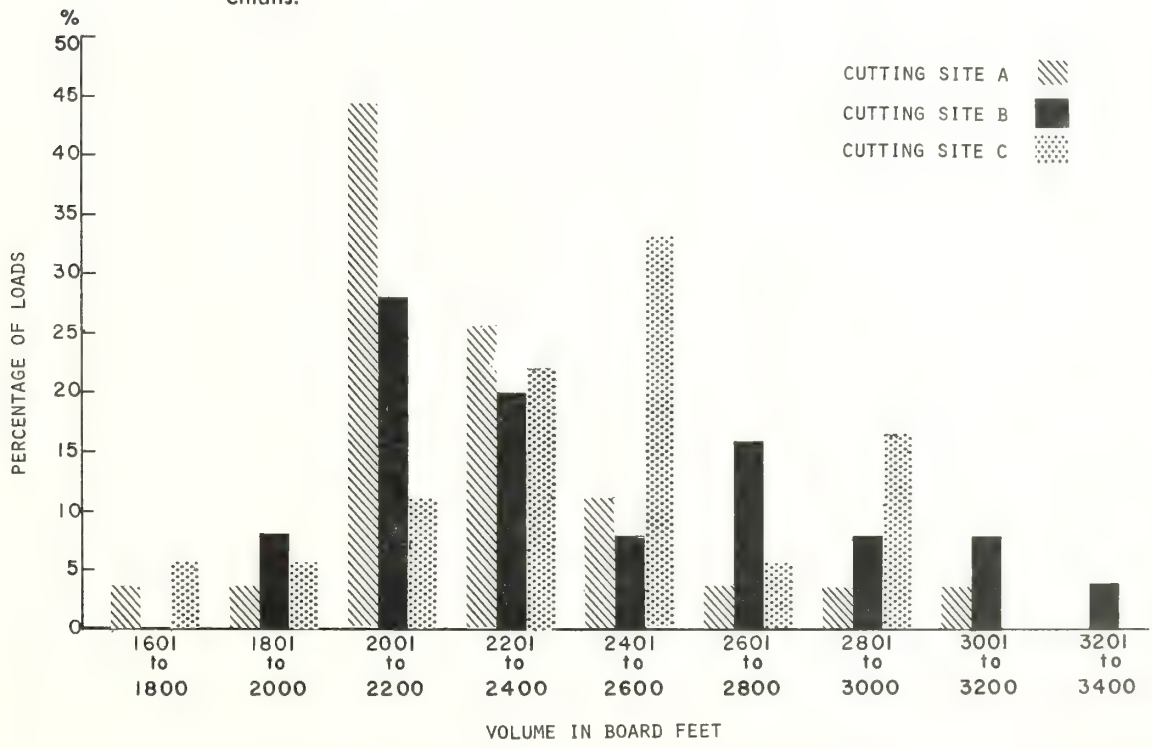


Table 2.—Variation in tandem truckloads of logs originating at a given cutting location

Factors	Load measurements			
	Weight	Volume Doyle	Volume Int. ¼	Volume
	Lb	*Fbm*	*Fbm*	*Ft³*
	CUTTING SITE A			
Max. load	37,520	3,118	3,505	666
Min. load	23,080	1,797	2,593	487
Ave. load	29,785	2,288	2,937	556
Std. dev.	3,599.9	274.0	245.9	44.7
	CUTTING SITE B			
Max. load	34,370	3,284	3,415	606
Min. load	21,930	1,864	2,140	396
Ave. load	26,976	2,450	2,722	488
Std. dev.	3,554.7	397.7	412.8	70.9
	CUTTING SITE C (1 driver only)			
Max. load	31,530	2,930	3,380	561
Min. load	23,410	1,782	2,350	420
Ave. load	27,745	2,393	2,896	504
Std. dev.	2,607.2	349.6	309.9	44.2

Table 3.—Variation in tandem truckloads of logs originating at a given cutting site and delivered by individual trucks

Load size	Weight	Board foot volume		
		Doyle	Int. ¼	Volume
	Lb	*Fbm*	*Fbm*	*Ft³*
CUTTING SITE A				
	TRUCK NO. 1			
Max. load	37,520	3,118	3,505	660
Min. load	25,610	1,919	2,610	508
Ave. load	30,718	2,433	3,075	583
	TRUCK NO. 2			
Max. load	30,770	2,392	3,065	588
Min. load	23,080	1,797	2,595	487
Ave. load	28,207	2,153	2,808	552
CUTTING SITE B				
	TRUCK NO. 1			
Max. load	34,370	3,284	3,415	607
Min. load	24,160	2,091	2,345	410
Ave. load	29,081	2,674	2,991	532
	TRUCK NO. 2			
Max. load	27,400	2,553	2,635	468
Min. load	21,930	1,864	2,140	396
Ave. load	24,296	2,166	2,406	433
CUTTING SITE C				
	TRUCK NO. 1			
Max. load	31,550	2,930	3,380	561
Min. load	23,410	1,782	2,350	420
Ave. load	27,724	2,392	2,896	504

Loads delivered by single-axle trucks averaged 9,000 pounds less than average loads for tandem-axle trucks. But for single-axle truckloads, the relative variation in weight and volume was nearly the same as the variation for tandem-axle truckloads (table 1). The remainder of this article will deal only with tandem-axle trucks.

The variation we found among truckloads of logs arriving at the seven mills from various cutting sites was not unexpected. Considering all the possible conditions that might affect the size of a load, it is natural that loads should vary. But similar variation was found for loads hauled from the subsamples representing specific cutting sites and trucks of the same carrying capacity and body configuration (table 2). An analysis of variance showed no significant difference due to cutting site.

Proceeding further, we checked truck differences by measuring loads hauled by individual trucks. Here is the first variable (driver) that causes significant variation among truckloads of logs. Statistical test (t-test) indicated significant differences between two like trucks hauling from the same cutting site.

Although individual load variations were less, the differences between maximum and minimum loads were still large (table 3). For example, on individual trucks, load weight differences ranged from 5,000 to 12,000 pounds and load volume differences ranged from 600 to 1,200 board feet, Doyle scale.

EFFECTS OF REDUCED LOAD VARIATION ON HAULING COSTS

Such large differences in truckload weight or volume obviously influence hauling costs per unit volume. The larger the load (within mechanical and legal limits), the lower the hauling cost per board foot.

Data from this study showed that there were four times as many underloaded trucks as there were trucks loaded to, or exceeding, legal weight limits. Therefore, opportunities exist for reducing unit hauling costs through hauling bigger average loads. Using representative costs and distances[2] for the five trucks

[2] Assumptions based on data on file at the Forest Products Marketing Laboratory, Princeton, West Virginia.

in this study subsample, we found that the reduction in truckload hauling costs would have ranged from $0.83 to $5.56 per thousand board feet, Doyle scale (example 1). These figures are based on the assumption that all trucks were loaded to a legal capacity of 32,000 pounds net or 44,000 pounds GVW.

DISCUSSION OF FACTORS INFLUENCING LOAD VARIATION

It has been shown that there is no significant difference between cutting sites where many possible load-affecting factors—weather, topography, and market condition—could cause load variation. It has also been shown that there is a significant difference between trucks hauling from a given cutting site. In this case, there are two factors which directly influence every load—the human element (people and their way of building a load), and the product being loaded (namely logs). It is these two we will consider here.

The human element in loading trucks includes the actions of two people: the driver who has the final say on when a load is complete, and the loaderman who operates the crane used to build the loads. (All loads in

Example 1: Cost Saving

Assumption[a] — Cost of hauling—$1/loaded mile
Hauling distance—50 miles one way
Legal net load capacity for tandem trucks in this study—32,000 pounds

Truck No.	1	2	3	4	5
Legal load cap. (lbs.)	32,000	32,000	32,000	32,000	32,000
Act. ave. load weight measured (lbs.)	30,718	28,207	29,081	24,296	27,774
Difference (lbs.)	1,282	3,793	2,919	7,704	4,226
Lbs./bd.ft. log meas.[b]	÷12.6	÷13.1	÷10.9	÷11.2	÷11.6
Add. bd. ft.[c] needed to bring load to legal capacity	102	290	268	688	369
Ave. measured volume hauled/load	2,433	2,153	2,674	2,166	2,392
Ave. potential volume/load	2,535	2,443	2,942	2,854	2,761
Act. transportation cost/MBF	$20.55	$23.22	$18.70	$23.08	$20.90
Potential transportation cost/MBF	19.72	20.47	17.00	17.52	18.11
Potential cost reduction/MBF	$ 0.83	$ 2.75	$ 1.70	$ 5.56	$ 2.79

[a]Realistic values for central Appalachian Mountain region.
[b]Calculation: Average weight (lbs.)/load ÷ average volume (bd. ft.)/load.
[c]Where additional timber hauled is of the same character as that hauled on previous loads.
Note: All board foot measures based on Doyle scale.

this study were loaded with a single line swing boom loader).

The actions of these two people control the size of the load carried in the available cargo space. They also influence the character of the load by their selection of logs for loading and the placement of those logs on the truck. (With hydraulic loaders or self-loaders, one man makes the decisions affecting load size.)

The maximum cross sectional load area (allowable cargo width times allowable cargo height) is governed by state laws that limit truck width and height. For log trucks, the maximum cross sectional load area is about 69 square feet. None of the loads measured in the study subsamples fully utilized the legal allowable cross sectional load space (table 4). Such under-utilization of load space can be attributed primarily to short stakes particularly on the tripping side.

Some loads did exceed legal width because of spread stakes. A few loads exceeded legal height because of high rounding above the stakes. The frequency of over-width and over-height loads depends in some measure on the efficiency of law enforcement in the area.

Although the maximum legal cross sectional end space was never used for any of our sample loads, we wanted to assess the loading efficiency in the end space that was used. The percentage of end space utilized gives us a measure of this efficiency. Notice in table 4 that end space utilization ranged from 63 to 90 percent. This spread of 27 points indicates that the loadermen and drivers had a substantial influence on load size through log placement. Another major cause of load size variation is the logs themselves. Logs that would make the best load may not be readily available because they are buried in the deck.

To assess the effect of log variation we looked at the makeup of the loads. We recorded the number of logs per load and the percentage of logs per load for one length class —14 feet long and over—and three diameter classes—under 14 inches in diameter, 14 to 20 inches in diameter, and over 20 inches in diameter. There was a noticeable disparity in the distribution of log sizes and number of logs per load (table 5). Most loads carried some of each size class. The average number of logs per truckload ranged from 18 for cutting site C to 36 for cutting site A.

The species of hardwoods that make up the timber stands in this region are many and greatly influence the character of the loads. As many as eight different species were recorded on individual loads from all three cutting sites. The average number of species per load was four from cutting site B, six from cutting site A, and seven from cutting site C. Only red oak occurred on all loads from cutting sites A and B. No species occurred on all loads from cutting site C although the oaks predominated (table 6).

The last factor we considered was sweep, which is often a reflection of both the species and the bucking practices of the loggers. Sweep has an unpredictable influence on load size since its effect can be magnified or reduced by loading methods.

Table 4.—Cross sectional end area and space utilization of loaded log trucks hauling from selected cutting sites

Load size	Cross sectional load area	Percentage of load space utilized
	Ft^2	Pct
CUTTING SITE A		
	TRUCK NO. 1	
Max. load	61.9	77
Min. load	52.4	67
Ave. load	56.8	72
	TRUCK NO. 2	
Max. load	61.7	73
Min. load	51.4	63
Ave. load	55.1	68
CUTTING SITE B		
	TRUCK NO. 1	
Max. load	54.2	90
Min. load	43.4	74
Ave. load	49.9	81
	TRUCK NO. 2	
Max. load	56.9	83
Min. load	41.5	71
Ave. load	48.1	79
CUTTING SITE C		
	TRUCK NO. 1	
Max. load	55.0	76
Min. load	41.2	66
Ave. load	49.4	69

Table 5.—Frequency of certain log characteristics by truckload and cutting site

Load size	No. of logs	Length over 14 ft.	Small end diameter			Species per load
			Under 14"	14"-20"	Over 20"	
	No.	*Pct*	*Pct*	*Pct*	*Pct*	*No.*
CUTTING SITE A						
			TRUCK NO. 1			
Max. load	46	67	85	58	19	8
Min. load	24	32	38	15	0	5
Ave. load	36	43	71	26	3	6.5
			TRUCK NO. 2			
Max. load	35	66	85	45	4	8
Min. load	29	24	54	15	0	4
Ave. load	31	45	68	31	1	6.5
CUTTING SITE B						
			TRUCK NO. 1			
Max. load	23	60	43	82	53	8
Min. load	15	12	6	20	4	1
Ave. load	19	36	27	52	21	4
			TRUCK NO. 2			
Max. load	26	47	59	68	66	8
Min. load	12	10	16	17	0	2
Ave. load	19	20	32	53	15	4.5
CUTTING SITE C						
			TRUCK NO. 1			
Max. load	23	94	78	75	31	8
Min. load	15	62	13	22	0	5
Ave. load	18	75	44	47	9	7

Table 6.—Distribution of species

Species	Cutting site A			Cutting site B			Cutting site C		
	Percent of load		Occurrence[a]	Percent of load		Occurrence	Percent of load		Occurrence
	Min.	Max.		Min.	Max.		Min.	Max.	
				Percent					
Basswood	0	44	56	0	35	28	0	29	89
Beech	0	9	4	0	10	8	0	9	56
Birch	0	14	41	0	12	8	0	6	11
Blackgum	0	0	0	0	0	0	0	21	33
Black locust	0	24	78	0	0	0	0	0	0
Butternut	0	7	4	0	0	0	0	0	0
Cucumbertree	0	32	78	0	18	20	0	2	78
Elm	0	0	0	0	0	0	0	9	28
Hickory	0	21	78	0	24	44	0	12	50
Maple, red	0	13	26	0	6	12	0	0	0
Maple, sugar	0	15	48	0	47	80	0	35	61
Oak, chestnut	0	25	59	0	18	28	0	10	22
Oak, red	15	83	100	19	100	100	0	53	94
Oak, white	0	6	11	0	28	36	0	75	56
Sycamore	0	0	0	0	0	0	0	11	6
White ash	0	47	67	0	25	56	0	19	28
Yellow-poplar	0	0	0	0	0	0	0	20	50

[a] Occurrence—percent of loads on which species occur.

Only logs with more than 10 percent sweep[3] were considered to have an effect on load characteristics. The average number of logs with sweep in each load ranged from 11 percent for cutting site A to 15 percent for cutting site B.

DISCUSSION OF LOAD FACTOR INTERRELATIONSHIPS

The variations that affect load weight and volume cause problems for log haulers. Laws and mechanical restrictions on the size of loads are based mostly on weight. Payment for log hauling is based primarily on volume.

Species is one factor that can affect load weight without having much effect on load volume or vice versa. For example, a 16-foot, 20-inch basswood log weighs 2,097 pounds. The same size log of red oak would weigh 2,824 pounds. The gross Doyle scale for both logs would be 256 board feet.

In addition to species, we checked (by use of multiple regression[4]) the relative importance of log characteristics and the influence of cross sectional load area and space utilization on load weight and volume.

This analysis showed that, in descending order, the most important factors influencing load weight were: percentage of logs over 14 feet long, cross sectional load area, and space utilization. The same three factors, plus percentage of logs 14 to 20 inches in diameter, are significant in determining load volume. However, the order of importance is not distinct. Also on occasion, one or more of the other variables become significant under a particular set of load conditions.

CONCLUSIONS AND RECOMMENDATIONS

This study showed that substantial load variation occurred even when factors such as truck type, cutting site, and driver influence were eliminated. It was not uncommon to find load variations of 10,000 pounds and 1,000 board feet for the same truck, driver, and cutting site.

Human factors influenced both load size hauled and payload space utilized. Our observations showed that four out of five trucks were underloaded from a legal weight standpoint. Even with present body designs, individual truckers could have increased the average load size (as measured by cross sectional load area) by about 15 percent.

A greater source of load variation was the logs themselves. Differences in log diameter and length, number of logs loaded, log weight, and species caused most of the remaining variation among loads. Logically, the longer, bigger, straighter logs gave better loads.

Our first recommendation is to increase stake heights. With longer stakes, loads could be built to approach legal height or weight, whichever comes first. For some trucks in this study, longer stakes would allow up to a 40 percent increase in cross sectional load area. But we must remember that this increase could overload trucks both legally and mechanically. And increasing load area may not reduce load variation because of human elements and log characteristics.

In the past, mill yard methods and equipment dictated that most log trucks be equipped to dump their loads. Therefore, short trippable stakes were used. Some loggers used removable extensions in these short stakes but they were cumbersome and not very popular. With the advent of new log yard equipment that can lift off partial or entire loads of logs without tripping, longer and more permanent standards can be used. Lengthening the stakes would be a cheap and easy way to increase payloads and reduce unit hauling costs. Furthermore, longer permanent stakes would give added safety to passing motorists and to the truck drivers themselves.

Our second recommendation is to sort logs at the landing prior to loading. With the rapid switch to hydraulic loaders in the Appalachians, the job of sorting and loading becomes easier and safer. Where these loaders are used, logs are often stacked as they are bucked. During the stacking process, the logs could be sorted as well. Sorts by length, diameter, and

---

[3] Percent sweep = $\frac{\text{Maximum departure from straight line minus 1 inch for each 8 feet in length}}{\text{Diameter}}$

[4] A. Jeff Martin. 1971. MULGRES: A computer program for stepwise multiple regression analysis. USDA Forest Serv. Res. Note NE-128, 5 p. NE. Forest Exp. Sta., Upper Darby, Pa.

general quality might allow better utilization of available truck space through more efficient log placement during loading.

Finally, we recommend that tandem-axle trucks be loaded to more effectively utilize cargo space by double tiering short logs. When mixed lengths are carried, special loading procedures should be followed. Since logs of similar diameter occupy the same cross sectional area regardless of length, it is logical that two 8-foot logs of similar diameter should be placed end to end.

Perhaps a better technique would be to carry two complete tiers of 8-foot logs or one tier of 8-foot logs and one tier of 10-foot logs. Where bunk and stake arrangements do not allow double tier loading, an alternative would be to line bunks and stakes with 16-foot logs and fill the cradle thus formed with two tiers of 8- and 10-foot logs. Published length distributions[5] indicate that the mixture of 8-, 10-, and 16-foot logs is sufficient to make this suggestion workable.

[5] Goho. Curtis D., and Paul S. Wysor. 1970. Characteristics of factory-grade hardwood logs delivered to Appalachian sawmills. USDA Forest Serv. Res. Paper NE-166, 17 p., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

Timson, Floyd G.
1974. **Weight and volume variation in truckloads of logs hauled in the central Appalachians.** NE. Forest Exp. Sta., Upper Darby, Pa.
9 p., illus. (USDA Forest Serv. Res. Paper NE-300)

Discusses the variation in weight and volume found among loads of logs hauled by truck in the central Appalachian Mountains. The elements which can cause load variation are discussed. It is shown that many elements, rather than one or two, cause loads to differ. Recommendations as to methods of reducing variation and increasing payloads are included.

OXFORD: 377.45: (371). KEY WORDS: Truck logging, log loading, logging, log transportation, load variability.

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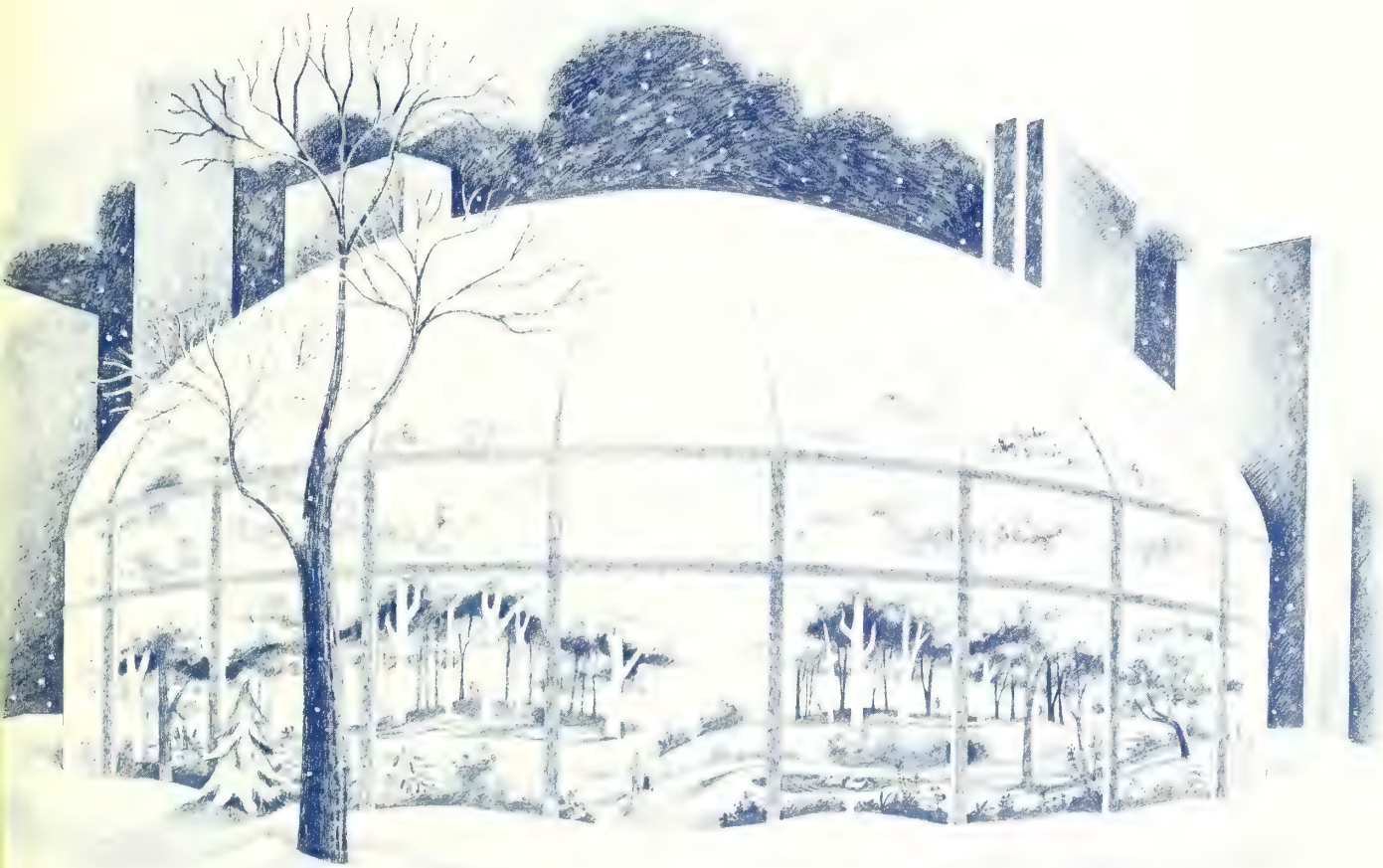
Future Leisure Environments



USDA FOREST SERVICE RESEARCH PAPER NE-301
1974

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MANUSCRIPT RECEIVED FOR PUBLICATION 5 JUNE 1973

Abstract

As an aid to policy- and decision-making about future environmental problems, a panel of experts was asked to predict the probabilities of future events associated with natural-resource management, wildland-recreation management, environmental pollution, population-workforce-leisure, and urban environments. Though some of the predictions projected to the year 2050 may sound fantastic now, the authors think that some of the events predicted may occur sooner than forecast.

Future Leisure Environments

TO GROW, indeed to survive, a democratically based technology-oriented society must anticipate and avoid changes that will detrimentally affect its basic life-support systems: soil, water, air, flora, and fauna. Otherwise that society is on a collision course toward extinction. Furthermore, the faster that changes occur within man-environment systems, the more critical it becomes to search the future so as to adjust present policies and programs for coping adequately with future environmental problems.

By searching out the prospects of what tomorrow's environments are likely to be, we can provide direction and scope to new policies that will insure a desirable future, a future in which man can live in harmony with nature. But the future must be specified, and obstacles along the way must be delineated so that a desirable course—no matter how diverse and challenging—can be charted.

That is the purpose of this paper: to probe the unexplored territory that lies ahead in our path to the future, and to forecast those points in time when relevant technological, social, ecological, and institutional changes are likely to occur. Based on a survey of experts' opinion, median dates and interquartile ranges are forecast for 125 future events cataloged into one of the following five categories: natural resources management, wildland recreation management, environmental pollution, population-workforce-leisure, and urban environments. Information is intended to stimulate the thinking of decision-makers in these five broad categories and to provide direction for formulating policies to deal with future environmental problems.

Although we are seeking to forecast important future environmental conditions, this study is not a crystal-ball undertaking. Other writers have suggested what man's condition will be in 1984 (*Orwell 1949, Huxley 1958*); in the next 20 years (*Michael 1965*); at the end of the twentieth century (*Wall Street Journal 1966*); or even a hundred years to a thousand years from now (*Stapleton 1931*).

Our projections can be doubted, and we hope readers will vigorously debate them. The more people who begin to think seriously about where we are headed, the better. We invite you readers to comment about the events we discuss here, and to offer your own ideas.

STUDY DESCRIPTION

The Delphi Technique

The research strategy used in this study is known as the Delphi Technique (*Helmer and Rescher 1960*). In ancient Greece, when one sought knowledge of the future, he consulted the Oracle of Delphi; today he consults the experts to determine what events are likely to occur in a given field. The technique derives its importance from the realization that projections of future events, on which public policy decisions must rely, are based largely on the personal insight of informed individuals rather than on predictions derived from well-established current theory.

Helmer and Rescher (*1964*) have described the philosophical basis of the Delphi technique as the process of combining expert opinions into a group consensus. The Delphi technique has proved extremely useful for long-range forecasting of technological developments, evaluating sociological-institutional events, examining the consequences of political alliances, devising war-prevention techniques, and determining economic growth indices. Results of these kinds of studies provide a basis for policy formulation and long-range planning (*Bright 1968*).

Instead of using the traditional approach toward achieving a consensus through open debate, the Delphi technique "eliminates committee activity altogether, thus . . . reducing

the influence of certain psychological factors, such as specious persuasion, unwillingness to abandon publicly expressed opinions, and the bandwagon effect of majority opinion" (*Helmer and Rescher 1960*).

The Delphi technique replaces direct debate with a series of questionnaires sent to a selected panel of experts. Successive questionnaires contain opinion feedback from previous panel responses. Inquiries about reasons given by various panel members are used to stimulate other panel members to consider points they may have overlooked and to reevaluate factors they had at first thought to be unimportant.

Panel of Experts

An important aspect of the Delphi procedure involves the selection of the panel of experts. Results of a Delphi survey are only as good as the expertise of the panel participants. Panel members were selected on the basis of their current literary or legislative contributions in one or more of several broad subject-matter areas. In this study, 405 of 904 experts (44.8 percent) initially enlisted remained to the end of the study.

Experts in natural-resources management made up more than half of the final panel membership; experts in environmental-pollution work made up 11 percent, and ecologists 10.4 percent. The expertise of the rest of the panel was divided equally between recreation-resources management, commercial-recreation equipment development, and population-dynamics specialists. About 4 of 10 panel members were employed by public land-management agencies, 2 in 10 by educational institutions, and 1.5 in 10 by communications industries. The remainder were divided among public regulatory agencies, legislative bodies, quasi-public environmental organizations, and industry.

The Delphi study proceeded through four rounds.

Round One

In round one, each expert was asked to list the most significant events he felt would have a 50-50 chance of occurring by the year 2000. Experts were instructed to consider only events that related to their own area of expertise. Panel members were instructed to assume an essentially stable political situation and sustained economic growth to the year 2000. The possibility of all-out nuclear war was excluded. Beyond these assumptions, panel members were asked to make their own assumptions about the future.

Round Two

For round two, events suggested in round one were summarized, edited, and grouped into three subject-matter areas: institutional and social events, natural-resources management and policy events, and events related to environmental technology. Three questionnaires, one for each of these subject-matter areas, were mailed to all panel members. Each respondent was asked to answer the questionnaire that contained events most closely related to his area of expertise (some experts were knowledgeable in all three areas), and to state the year in which he felt each event had a 50-50 chance of occurring. Panelists were also given the opportunity to indicate if they felt an event would never occur.

In summarizing round-two events, we found that many median estimates of the date an event would probably occur went beyond the year 2000. Nevertheless, all events were retained for consideration in subsequent rounds.

Round Three

In round three we sent respondents a graphic summary of the range of dates for round-two events and another questionnaire. The summary contained an event-by-event description of the interquartile range and median point for the distribution of dates predicted for events listed in round two. The interquartile range contains the middle 50 percent of all dates forecast for any one event. The median is the center of this range; that is, the middle item in an array of dates.

In the graphic results sent to each respondent, we placed an asterisk at that point in time where he indicated (in round two) that each event would occur. Thus, each respondent could judge where his response fell rela-

tive to responses of all other panel members who responded to the same event. In responding to each round-three event, each panel member was asked to consider:

1. His round-two responses in light of the response distributions of all other panel members.
2. To change his round-two estimates if he cared to.
3. If his round-three estimates fell outside the graphed interquartile range for any given event, he was asked to justify his response.

Round Four

Round four was similar to round three—the same summary information was provided—but in addition, major arguments presented in round three were summarized by event. Panel members were asked to consider these arguments in arriving at their final decisions as to when each event was likely to occur.

Results were summarized at the end of round four. Through successive rounds, the distributions of responses around the median-year prediction were continually reduced. In some cases, the median changed. Throughout all four rounds, if a panel member failed to respond to a questionnaire, he was dropped from the panel.

RESULTS

Events contained in the Delphi questionnaire are grouped into five categories: natural-resource management, wildland-recreation management, environmental pollution, population-workforce-leisure, and urban environments. Figures 1 through 5 summarize events in each category.

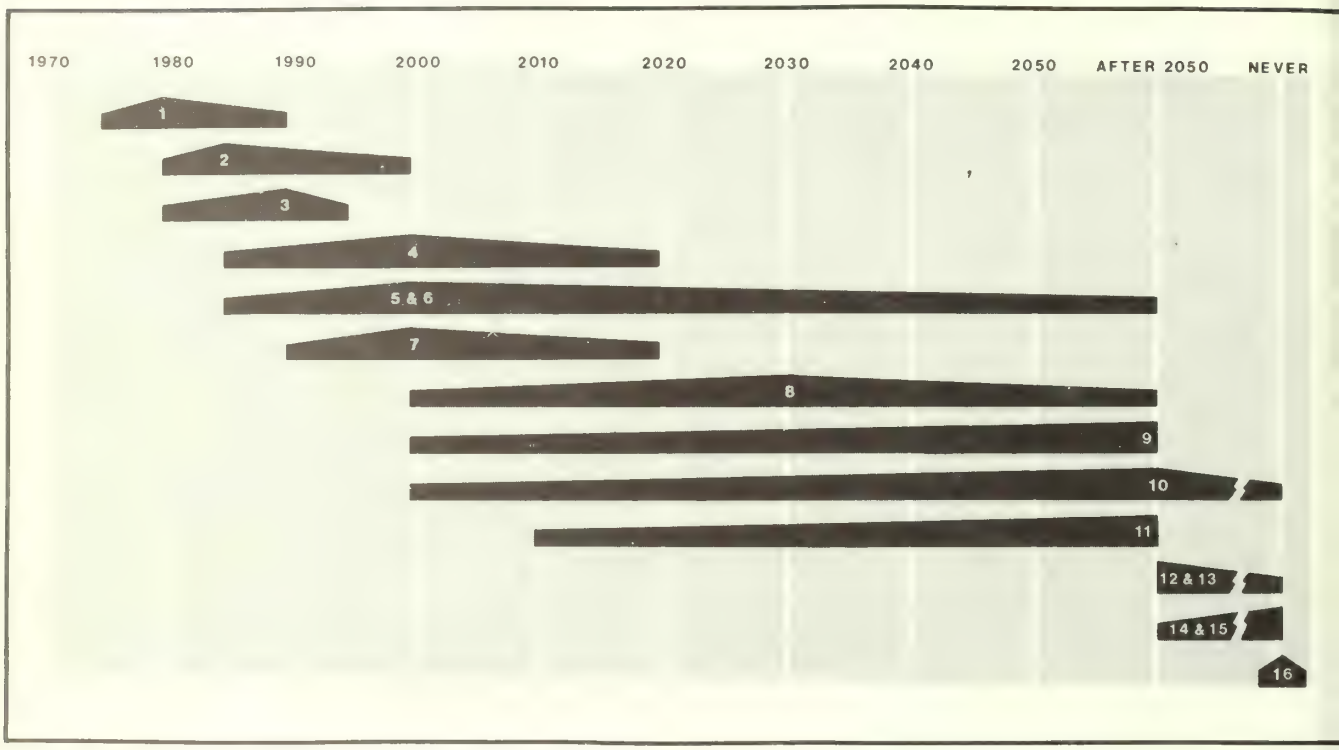
For each event, a horizontal bar is used to describe the interquartile range of panel predictions. The median prediction is represented by the peak of each bar. The length of the interquartile bars indicate the degree of consensus among experts. In our discussion of results we will limit our comments to median dates.

For example, the first event described in figure 1 is: economic incentives to encourage private citizens to manage their land for fish and wildlife. The median year predicted for this event was 1980; that is, half the experts who responded to the event felt it would occur before 1980, and half felt it would either occur after 1980 or would never occur. The interquartile range, containing half of the panel member predictions, extends from 1975 to 1990. One-fourth of the panel members felt that the event would occur before 1975, and one-fourth felt that it would either occur after 1990, or would never occur.

Figure 1

CONSENSUS OF PANEL ON NATURAL-RESOURCE MANAGEMENT

(Medians and interquartiles)



NATURAL-RESOURCE MANAGEMENT

1980

1. Economic incentives to encourage management of private land for fish and wildlife.

1985

2. Tax credit to private landowners who provide scenic amenities.

1990

3. Federal land, water, and air use plan established

2000

4. National land-use zoning policy established.
5. Preempted public recreation land replaced with comparable land.
6. Coordinated environmental planning between government and private enterprise.
7. Most marine and estuarine areas managed for fish and wildlife habitat.

2030

8. Electrical power rationed by national priorities.

After 2050

9. National per-capita land requirement established.
10. Some natural and man-made lakes heated for swimming.
11. Viable international agreement on allocation of the world natural resources.
12. Shoreline along navigable rivers placed in public ownership.
13. All intensively developed recreation facilities under public management.

Never Occur

14. All water and land recreation resources under federal control.
15. Cease construction of new highways.
16. All recreation facilities provided by commercial enterprise.

Natural-Resource Management

(*Figure 1*)

In the discussion that follows, the numbers in parentheses refer to events in the figures. Most panel members predicted a rapidly expanding governmental role in natural resources management. The 1980 economic incentives offered private landowners who manage for fish and wildlife (1) will broaden by 1985 to include tax incentives for providing scenic amenities (2)

The Federal role in coordinating natural resource planning will expand from establishing the first land, water, and air-use plan in 1990 (3) to a national land-use zoning policy in 2000 (4). By 2000 environmental planning will be effectively coordinated between all levels of government and private enterprise (6). Also by 2000, land-use patterns will stabilize, land preempted for one use being replaced with comparable land (5). All natural resources, including marine and estuarine areas (7), will be under intensive management. Growing demand for electrical power will require rationing according to a national priority system by 2030 (8).

Although panel members disagreed about the exact year, most foresaw continuing expansion in national and international planning and control of natural resources after 2050 (11). A national per-capita land requirement will be established after 2050 (9). Growing demands, particularly for recreation resources, will require that natural resources be used more intensively. Heating of manmade lakes to allow year-round recreation (10) and public control of shoreline along all navigable water (12) will occur after 2050. Because of a dwindling resource base, public agencies will operate most resource-based recreation facilities (13).

Although most panel members agreed that government will play an increasingly important role in natural-resource management and planning, they felt that control over use of privately owned resources will always remain with private owners (14, 16). They also felt that construction of new highways will never cease (15).

Wildland-Recreation Management

(*Figure 2*)

Expert opinions reflect an increasingly important role of recreation in influencing wildland management and policy. By 1980, restrictions will start on recreational use of wildland areas. Glass containers will be prohibited from wildland recreation areas (5), and use of all off-road recreational vehicles will be restricted to designated areas (3). To expand the use of scarce resources, recreation activities in an area will be assigned time periods (1). Computers will be used to advise recreationists where to go for recreation (4), and information and education efforts will be expanded to improve the quality of recreation experiences (2).

Restrictions on recreation use will also be expanded to maintain the quality of recreation experiences. By 1985, restrictions will be placed on the number of people allowed to use a wilderness or remote area at one time (10). Maximum noise levels will be established to maintain the quality of recreation experiences and environments (6). The recreation experience itself will change, with facilities such as cable TV hookups available at most campgrounds (9); and acceptable restrictive management techniques will be employed to control recreation use patterns (7) Also by 1985, economic incentives will be available to private landowners who open their land for public recreation (8).

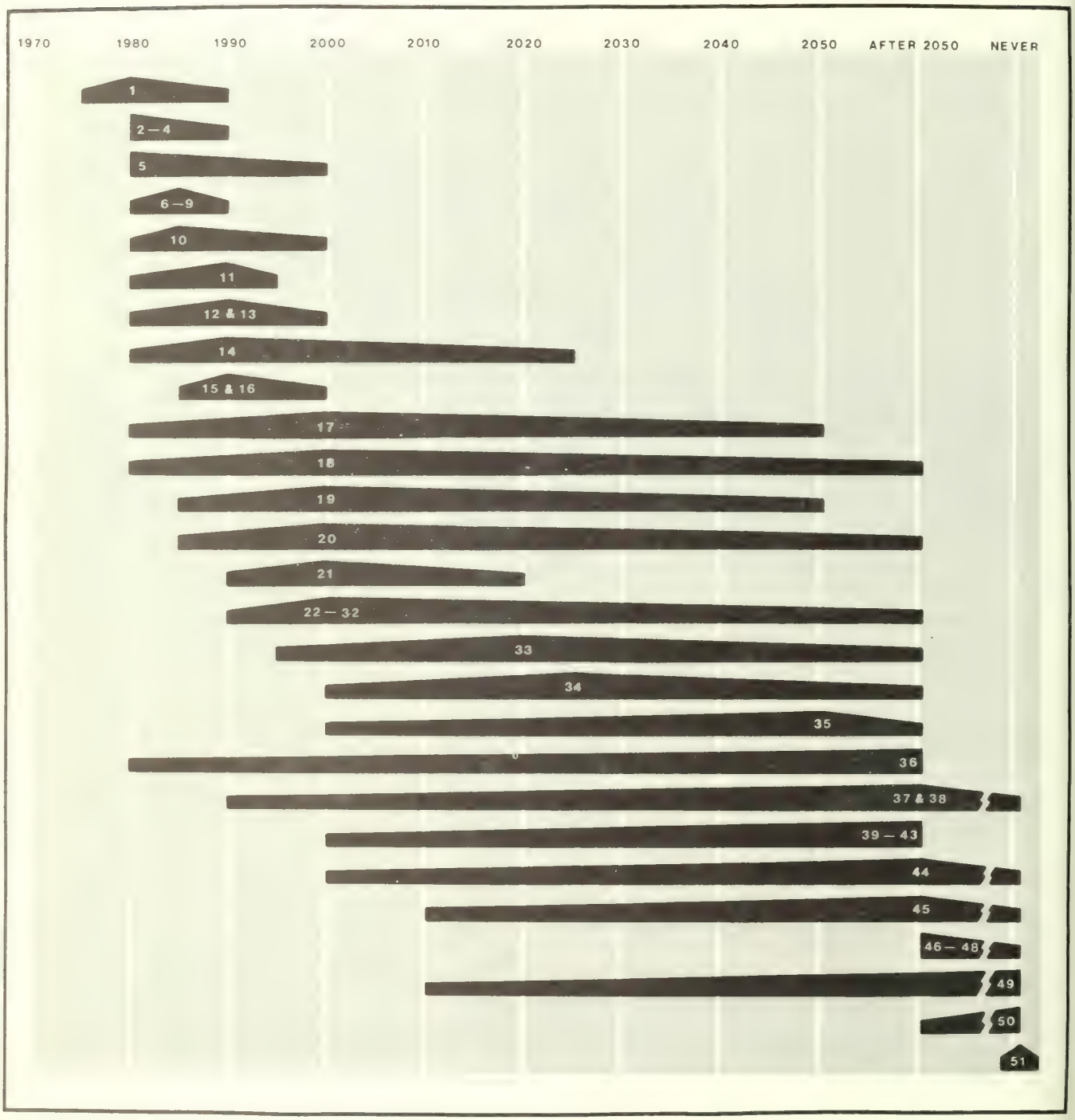
Increasing recreation pressure will require additional restrictions on recreational use of wildland resources by 1990. Restrictive management techniques will be used to reinforce heavily used recreation areas and to direct use patterns (14). Public recreation areas will be assigned maximum carrying capacities, and use will be kept at or below capacity levels (12). Recreation use of developed public recreation facilities will be by reservation only (16). Maximum recreational boat motor sizes will be set for public water bodies to alleviate use pressures and to prevent environmental degradation (15). Fishermen will pay for the use of salt-water fish resources (11).

Growing recreation demands on wildland resources will require that increasing controls be

Figure 2

CONSENSUS OF PANEL ON WILDLAND-RECREATION MANAGEMENT

(Medians and interquartiles)



WILDLAND-RECREATION MANAGEMENT

1980

1. Different recreation activities allocated specific time periods for the same recreation-management area.
2. Information about the flora, fauna, and historical features provided at most public recreation areas.
3. Use of off-road vehicles restricted in public recreation areas.
4. Computers used to advise recreationists where to go for recreation.
5. Cans and glass containers prohibited from wildland recreation areas.

1985

6. Maximum noise levels enforced in recreation areas.
7. Recreationists accept restrictive management procedures such as closing or altering recreational use to maintain and preserve vegetation, water quality, and wildlife.
8. Economic incentives available to private landowners who open parts or all of their land for public recreation.
9. Cable TV available at most campgrounds.
10. Use of wilderness areas restricted to maintain or enhance the quality of a wilderness experience.

1990

11. Salt-water fishermen required to purchase federal fishing licenses.
12. Public recreation lands assigned a carrying capacity—the maximum level of use an area can sustain without loss of natural values—and use will be kept at or below that level.
13. Year-round skiing on artificial surfaces.
14. Management techniques, such as wear-resistant footpaths, electronic guide systems, and fences to direct recreation users, accepted for managing outdoor recreation areas to allow increased use without adversely affecting the resource.
15. Recreational boat-engine size restricted on all public water bodies.
16. Camping in public areas by reservation through a national information-retrieval system.

2000

17. Wilderness-area management includes seeding, planting, fire control, and other intensive management techniques to maintain the wilderness environment.
18. Remote sensing devices used to monitor park use.
19. Captive rearing commonly used to rear endangered species for release into the wild.
20. Animal migrations monitored by satellite.
21. Non-polluting propulsion methods, such as electric power, replace internal-combustion engines in recreational vehicles.
22. Travel in large parks by systems that minimize transportation effects on natural resources; for example, air transport, underground rapid transit, tramways, and cable cars.
23. Certification of wilderness users required.
24. Airstrips and helicopter pads established at most popular recreation areas.
25. Utility lines within sight of recreation areas placed underground.
26. Waste-disposing bacteria incorporated into recreation equipment.
27. Permits used to control all resource-based recreation.
28. Photography and observation are primary uses of wildlife resources.
29. Small private recreational submarines used as commonly as snowmobiles are used today.
30. Motorized vehicles excluded from hunting areas during hunting season.
31. Most resource-based recreation areas lighted for night use.
32. Extensive areas in arid regions irrigated to enhance recreational opportunities.

2020

33. Man-made islands created solely for recreation.

2025

34. Half the states permanently revoke licenses of fish-and-game-law violators.

2050

35. The last acre of wilderness is designated.

After 2050

36. Wilderness-management philosophy allows more intensive recreational developments.
37. Only foot travel allowed in major public parks.
38. The first tract of land will be withdrawn from wilderness status.
39. Self-contained underwater resorts.
40. Hover-craft used as commonly for recreation as the snowmobile is used today.
41. Jet-powered backpacks sold at prices accessible to middle-income families.
42. Hunting legal only on specified game lands.
43. Robots used for park maintenance and public-information programs.
44. One-man, low-speed helicopters commonly used for transportation within wilderness areas.
45. Wildlife populations managed by birth-control techniques.
46. Hunting firearms utilize laser beams.
47. Rivers constructed strictly for recreation.
48. First park established on the moon.
49. Fees at public recreation areas set to cover all capital and maintenance costs.
50. National parks and recreation lands open for daytime use only.
51. Public allowed to use all rural land for hunting and fishing.

placed on use of recreational resources. By 2000, wilderness-area management philosophy will, by necessity, change to more intensive management to maintain the wilderness environment (17). Permits, used to control all resource-based recreation (27), will also include certification for certain user groups, such as wilderness users (23).

Wildland recreation areas of 2000 will be vastly different from those of today. Only travel systems that have a minimum physical and visual impact on park environments will be allowed (22). Only recreation vehicles that employ non-polluting propulsion systems will be allowed in recreation areas (21) Popular wildland recreation areas will be serviced by air (24). Park environments will be aesthetically improved by underground placement of all utility lines (25).

Technology will assist the park manager of 2000, as well as create new management problems for him. Artificial lighting will extend use of resources well into the night (31), and remote sensing devices will be used to monitor park use (18). Waste-disposing bacteria, incorporated into recreational equipment, will reduce sanitary disposal problems (26). Extensive irrigation of arid regions will broaden and enhance recreational opportunities (32). Technology will also create recreational opportunities (32). Technology will also create recreation equipment that will provide challenging management problems. For example, experts felt that by 2000, small private submarines will be in common use (29).

Rather than rely on natural reproduction, the wildlife manager of 2000 will utilize cap tive rearing to raise endangered species for release into the wild (19). He will monitor wildlife migrations by satellite to assist in developing management programs (20). Controls will be placed on hunting; motorized vehicles will be excluded from hunting areas during hunting season (30). But by 2000, the primary use of wildlife resources will change from hunting to non-consumptive uses like photography and observation (28).

Although the picture drawn by the experts for beyond the year 2000 becomes quite hazy, trends in events to that time appear to continue into the 21st century. Dwindling open space for wildland recreation will require that by 2020 islands be constructed for recreation space (33). The last acre of wilderness, as currently defined, will be designated in 2050 (35). Wildlife resources will be much more intensively managed, at least half the states permanently revoking licenses of fish- and game-law violators (34).

Although experts were not specifically asked to forecast events far into the 21st century, they named many events that they felt would occur sometime after 2050. Most experts felt that, beyond 2050, wilderness-area management philosophy will by necessity change to include management for intensive recreation activities, and wilderness aspects will be reduced in importance (36). In fact, land will start to be withdrawn from wilderness designation (38). Foot travel will be the only form of transportation allowed within major parks (37).

Technology will have a strong impact on wildland-recreation management after 2050. New recreation equipment—hovercraft (40), jet-powered backpacks (41), and one-man helicopters (44)—will be in common use for recreation purposes. Self-contained underwater resorts (39) and rivers constructed for recreation (47) will add significantly to the available supply of recreation resources. A few panel members felt that sometime after 2050 the first park will be in operation on the moon (48). Back on earth, robots will assist the park manager in park maintenance and public-information programs (43).

Some panelists felt that user fees at public recreation areas will eventually be set to cover all costs of providing recreation (49), that public areas will be open only for daytime use (50), and that the public will be allowed to use rural lands for recreation, regardless of ownership (51). However, most experts felt that these events would never occur.

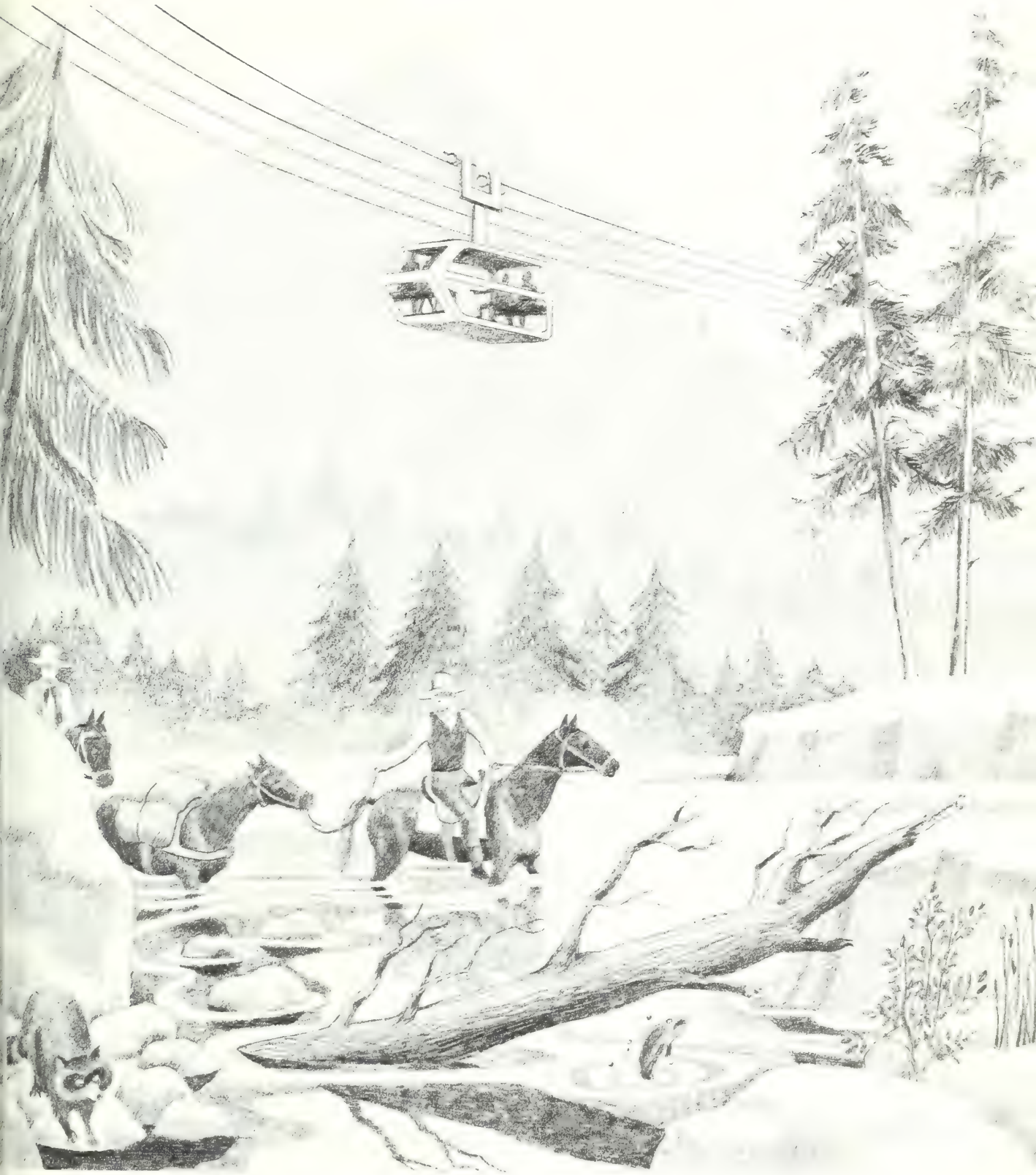
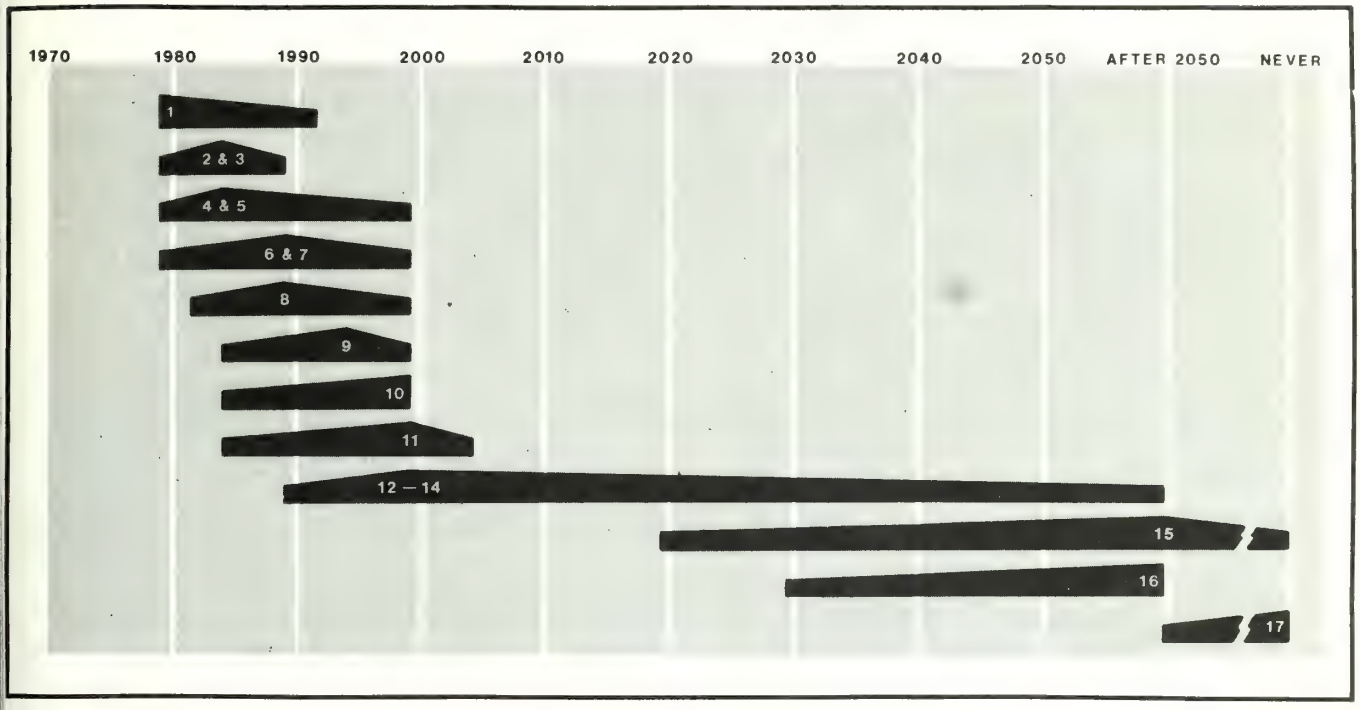


Figure 3

CONSENSUS OF PANEL ON ENVIRONMENTAL POLLUTION

(Medians and interquartiles)



ENVIRONMENTAL POLLUTION

1980

1. Tax credits to industries that practice pollution control.

1985

2. Accurate simulation models for effects of air and water pollution.
3. Half of the states establish standards for outdoor advertising.
4. Effective controls on auto and airplane exhaust emissions.
5. Federal testing for environmental impacts of all consumer products.

1990

6. Consumers accept major costs of pollution control.
7. Companies that do not comply with pollution standards will be closed.
8. An operational nationwide environmental monitoring system.

1995

9. Commercial products packaged in non-polluting containers.

2000

10. International agency established to halt further air water pollution.
11. International agency established to contain accidental pollution on the open sea.
12. Toxic effects of pollutants determined and tolerance limits set.
13. Federal Reserve chartered banks cease to finance companies that pollute the environment.
14. Only biodegradable chemicals allowed to be discharged directly into the environment

After 2050

15. Most major lakes and rivers purified to support the kind of aquatic life they had in 1880.
16. Most waste products recycled and utilized.

Never Occur

17. Political boundaries realigned to coincide with natural ecological boundaries.

Environmental Pollution

(*Figure 3*)

Experts showed remarkable agreement on the years in which they felt major events related to environmental pollution would occur. Most felt that by 1980 tax credits will be offered to industries that practice pollution control (1). By 1990, however, pollution standards will be strongly enforced, and companies that do not comply with pollution standards will be closed (7).

Concern for landscape aesthetics will lead to half the states passing legislation to control outdoor advertising by 1985 (3). Also, by that year, effective controls will be placed on auto and air exhaust emissions (4). Consumer products that have adverse environmental effects will be banned from production (5).

By 1990, environmental data, collected through a nationwide monitoring system, will be used to accurately simulate the effects of pollutants (8, 2). Consumers will accept the major costs of effective pollution control (6). By 1995, most commercial products will be packaged in discardable containers that do not pollute the environment (9).

By 2000, strict pollution controls will be established on both the domestic and international scenes. An international agency will be established to halt further air and water pollution (10, 11). Although predictions varied considerably among panel members, other events predicted for the turn of the century include: setting exact tolerance limits for various pollutants (12), allowing only biodegradable chemicals to be discharged directly into the environment (14), and disallowing federal reserve chartered banks to finance companies that are known to pollute the environment (13).

Although panel members felt that most waste products will be recycled (16) and that lakes and rivers will be purified to their 1800 level (15), panel consensus was that these events would not occur until after 2050. Only one out of three experts felt that political boundaries will ever be realigned to coincide with natural ecological boundaries (17)

Population-Workforce-Leisure

(*Figure 4*)

A growing population with changing attitudes toward leisure will have a major impact on institutional and social structures in the years ahead. By 1985, experts predicted an average 4-day, 34-hour week (2). Employers will provide a leisure consulting service for their employees (1). Data on leisure activities and interests will become a regular part of the U. S. Population Census by 1990 (4). In response to increased travel and changing leisure interests, public schools will operate continually, with staggered vacation periods throughout the year (3). Most homes will be equipped with video tape systems for entertainment and education (5).

Panel members disagreed about many of the events with a median prediction year of 2000. But the median predictions indicate that 500 miles will be a reasonable one-way distance for the average family to travel on a weekend (7). In the year 2000, tax incentives will be offered to employers who include employee recreation facilities in the design and construction of new plant facilities (6).

Both the structure of leisure and social attitude toward leisure will change substantially by the year 2000. "Weekends" will be distributed throughout the week (9), thereby effectively increasing the supply of recreation facilities. With an average retirement age of 50 years (8), people will enjoy more total leisure during retirement. In response to abundant leisure, the role of public schools will expand to provide for recreational needs of the entire community (11). Middle-income families will vacation as commonly on other continents as they vacation in the United States today (13). Panel members also felt that by the year 2000 the work ethic will assume a smaller role in governing society, and leisure will become an acceptable life style rather than a reward for work (10).

An attempt will be made to control population growth through tax incentives in 2000 (12). But panel experts felt that eventually a mandatory population-control program will be necessary (15).

Panel members agreed that some time after

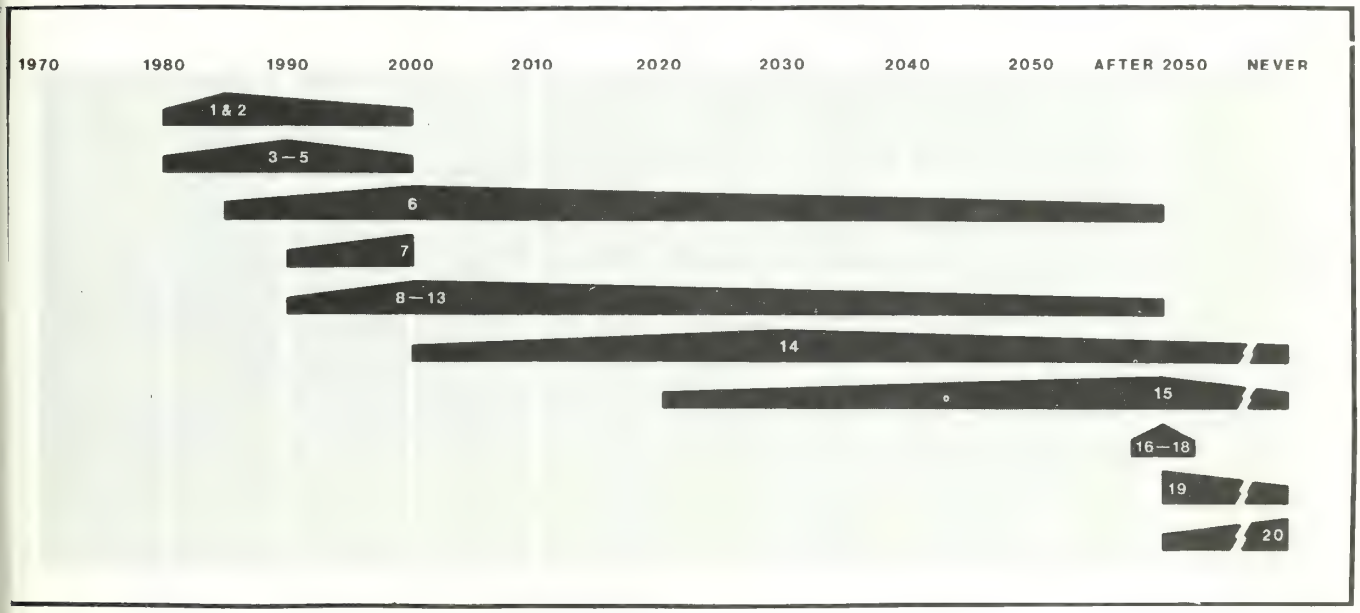
2050, people will have an average annual vacation of 3 months (16). They will enter the work force at an average age of 25 (19) and live to 100 years (17). Experts were about equally divided on the proportion of total work force that will eventually be required to produce all goods and services for the entire population. Half the panel felt that 20 percent of the total work force could accomplish this sometime after 2050, while others felt that this would never occur (18).

Although some panel members thought it possible, most felt that compulsory genetic measures would never be established to improve the quality of the human race (20).

Figure 4

CONSENSUS OF PANEL ON POPULATION-WORKFORCE-LEISURE

(Medians and interquartiles)



POPULATION-WORKFORCE-LEISURE

1985

1. Companies will consult employees on what sort of recreation activities would be best for their physical and mental health.
2. Most people work a 4-day 32 hour week.

1990

3. Public schools open year-round with staggered vacations.
4. U. S. Census of population includes questions on the recreation activities and needs.
5. Most homes have video-tape systems.

2000

6. Employers given tax incentives to include recreation facilities in plants.
7. Fve hundred miles is a reasonable one-way distance to travel for a weekend.
8. Average retirement age is 50 years.
9. "Week-ends" distributed throughout the week.
10. Leisure is an accepted life-style.
11. Public schools function to serve the recreation needs of the entire community.
12. Attempt to control population through tax incentives.
13. Middle-class Americans vacation on other continents as commonly as they vacation in the United States today.

2030

14. Most middle-income families own their own vacation home.

After 2050

15. Nationwide mandatory population control.
16. The average worker has a 3-month annual vacation.
17. The average lifespan is 100 years.
18. Twenty percent of the available workforce used to produce goods and services for the entire population.
19. Average entry into the workforce at 25 years of age.

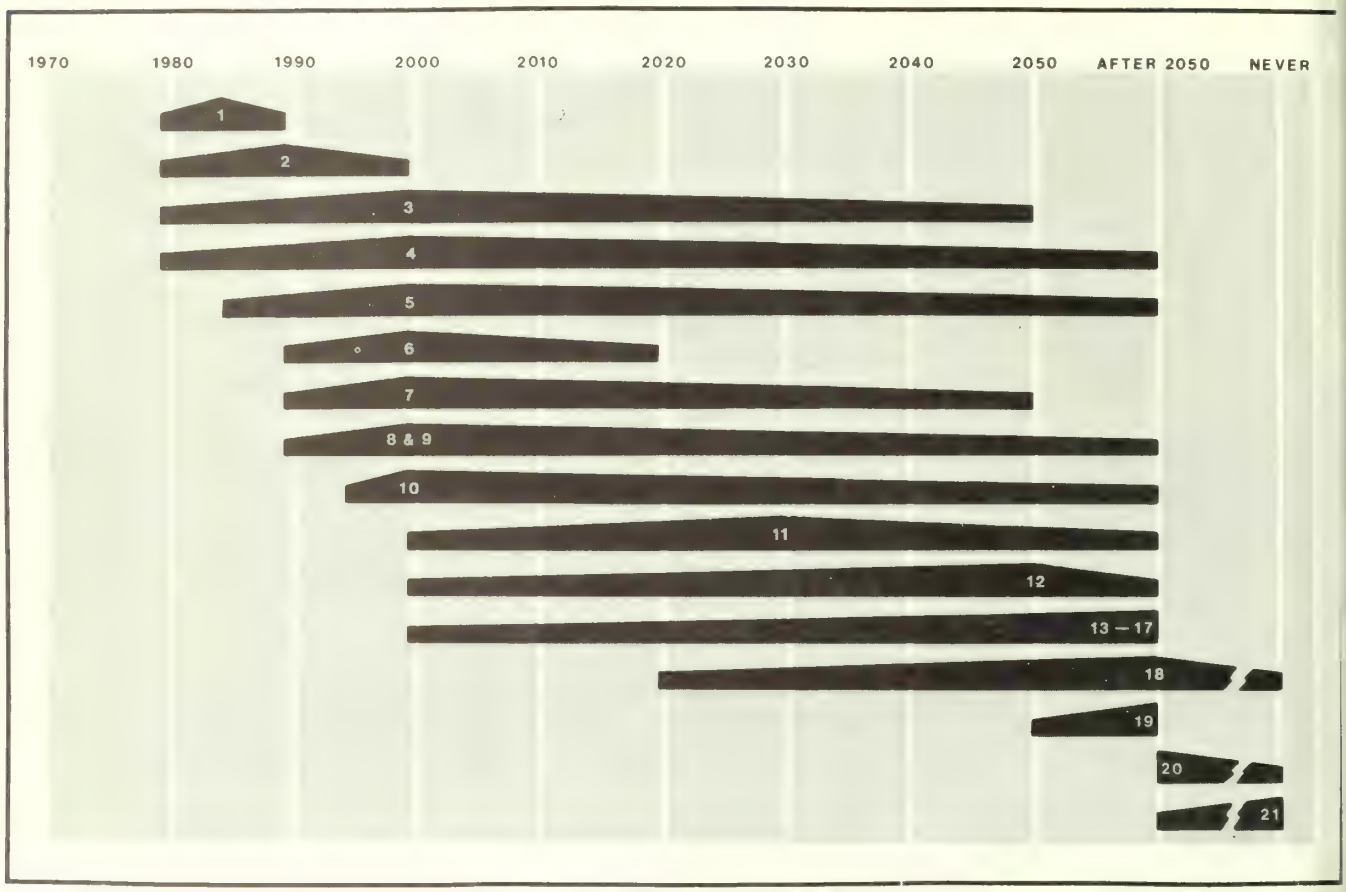
Never Occur

20. Compulsory genetic measures initiated to improve the human race.

Figure 5

CONSENSUS OF PANEL ON URBAN ENVIRONMENTS

(Medians and interquartiles)



URBAN ENVIRONMENTS

1985

1 Special fishing areas established in urban areas for the handicapped, elderly, and children.

1990

2. Small private aircraft excluded from metropolitan airports.

2000

3. Cemetery land and other open land in urban areas used for recreation.
4. Simulated indoor environments available that provide recreational opportunities now available only in the outdoors.
5. All water reservoirs open to public recreation.
6. Only non-air-polluting vehicles allowed in urban areas.
7. Artificial turf used in most public field sports areas and on some golf courses.
8 Green space preserved between most metropolitan areas.
9 Some city parks or parts of parks enclosed in all-weather protective bubbles.
10 Computers used to direct and control movements of individual transportation units.

2020

11. Most metropolitan areas provide adequate outdoor-recreation opportunities so that most urban residents do not feel the need to go to the country for recreation.

2050

12. "Camping" available in multi-story structures similar to parking garages.

After 2050

13. Roofs of many downtown buildings used as public playgrounds.
14. New urban growth displaced to relatively uninhabited regions.
15. High-speed public-transit systems built between most urban areas and major rural recreation facilities.
16. Most city blocks have a mini-park or play lot.
17. Ninety percent of the U.S. population lives in urban areas.
18. Apartment structures designed so that they can be detached and moved to recreational areas.
19. Self-contained floating cities with year-round residents.
20. Self-contained underwater cities.

Never Occur

21. Transparent roofs cover most cities.

Urban Environments

(*Figure 5*)

Panel members agreed that improved planning and technology will combine to make urban environments much more enjoyable in the future than they are today. By 1985, more emphasis will be placed on providing recreational services for specific urban population groups. For example, experts felt that special fishing areas will be established in most urban areas for the handicapped, elderly, and children (1).

By 1990, panel members predicted that private aircraft will be excluded from metropolitan airports (2). Controls on urban transportation will expand greatly by year 2000, when only non-air-polluting vehicles will be allowed in downtown urban areas (6). Computers will be used to direct and control movement of individual transportation units (10).

The urban area of 2000 will be attractive and livable. More land will be provided for leisure enjoyment; and cemeteries (3), water reservoirs (5), and added green space will be opened to recreational use (8). Leisure-serving facilities, like city parks and playfields, will be covered with artificial turf to sustain heavy recreation pressure (7), and some areas will be protected with all-weather bubbles to allow year-round use (9). Panelists even predicted that natural environments will be simulated inside man-made structures to provide urban residents with recreational opportunities now available only in the outdoors (4).

Panel members felt that by 2020, most urban areas will contain adequate recreation facilities so that the majority of residents will not feel the need to go outside their city for outdoor recreation (11). Recreation facilities will be developed in and near urban areas so that by 2050 even overnight camping facilities will be found within urban areas (12).

Panel members predicted a continual expansion of leisure-serving facilities beyond 2050: roofs of downtown buildings will be used as public playgrounds (13), mini-parks or play lots will be provided on each city block (16), and living structures will be designed so that they can be separated for movement to distant recreation areas (18). High-speed transit systems will eventually be available that connect major urban areas with wildland recreation areas (15). Although they predicted that 90 percent of the United States population will live in cities (17), panel experts felt that sometime after 2050 all new urban growth will be displaced to remote, relatively uninhabited regions (14). The form of urban development will change drastically after 2050, and self-contained floating cities and underwater communities will serve new urban growth (19, 20). Although some panel members felt it would occur, most felt that transparent roofs will never be constructed to cover major cities (21).

SUMMARY

In an era when momentous long-term decisions about man and his environment must be made, similar attention should be given to the underlying prediction-making process upon which all planning must be based. For example, the United States government staked 20 billion dollars on inventing a future that included placing a man on the moon by 1970. Similarly, many other potential *futures* are open to man. In this study we have examined 125 aspects of probable man-resource futures.

Short-term (5-year) forecasting—upon which many of today's man-resource management decisions are based—has the advantage of being able to extrapolate from existing trends. But in many man-resource relationships, long-range forecasts are needed that consider future breakthroughs in technology that may appear and interact before a specific future event occurs. Thus the variables and contingencies of most futures beyond 5 years from now can only be assessed intuitively.

Since the use of intuitive forecasting as a basis for long-range planning is unavoidable, we have attempted to obtain this intuitive judgment as systematically as possible from persons who are recognized experts in the areas of concern—ranging from future urban environments to future wilderness-management situations.

You may feel that some of our forecasts are fantastic, unbelievable, away out. Perhaps;

but consider the simple fact that man began to fly only in the early 20th century, and today he uses space ships to reach beyond his own solar system for answers about the universe.

Jules Verne once said, "What man can imagine, man can do". We have presented here a glimpse of only a few events that experts imagine will happen in the decades ahead, and even beyond. If the results of past predictions of man's progress are any indication of the likelihood that the events listed here will occur, then we can only suggest that in all probability many of the events will undoubtedly occur sooner than forecast.

Here comes tomorrow. Will we be ready?

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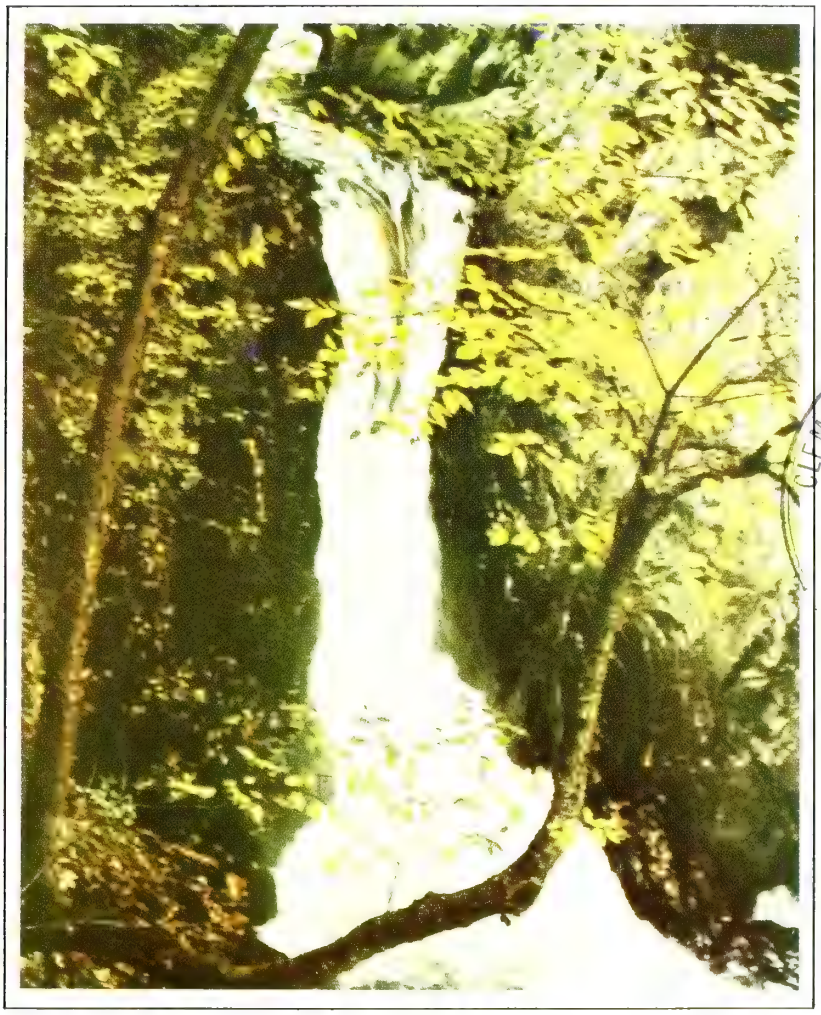
A Comparison of VIEWER REACTIONS to Outdoor Scenes and Photographs of Those Scenes



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MANUSCRIPT RECEIVED FOR PUBLICATION 15 MARCH 1973

A Comparison of VIEWER REACTIONS to Outdoor Scenes and Photographs of Those Scenes

ABSTRACT

A color-slide projection or photograph can be used to determine reactions to an actual scene if the presentation adequately includes most of the elements in the scene. Eight kinds of scenes were subjected to three different types of presentation: (A) viewing the actual scenes, (B) viewing color slides of the scenes, and (C) viewing color photographs of the scenes. For each scene, responses to each of the three treatments were compared statistically and graphically. On-site reactions to scenes provided quantitative measures of the positive effects that some forest environments have over some man-made environments.

PHOTOGRAPHS of outdoor environments play an important role in the competitive advertising and educational strategies designed to maintain, enhance, or change those environments. Photographs are used to measure, document, inform, and—frequently—change public attitudes and policies about important natural-resource issues.

Pictures of outdoor environments are used in a wide variety of commercial advertisements ranging from the background scenes in cigarette adds to promotion of outdoor recreation equipment. Consequently, resource planners and managers, landscape architects, information-education specialists, photo-journalists, advertising executives, and private citizen groups are interested in knowing how effectively a photograph duplicates or changes public opinion or feeling about an actual scene.

A review of literature failed to uncover any scientific studies that answer the question of possible difference between reactions to photographs and reactions to actual scenes. Nonetheless, a certain segment of the scientific research community argues that the connotative aspects of the meaning of a scene must be obtained from respondents at the time they view the actual scene. Other researchers suggest that there may be a strong positive correlation between connotative reactions to a scene and a comprehensive photograph of that same scene.

Overall results of our experiment, by the USDA Forest Service and the Newhouse Communications Center at Syracuse University, indicate that if a photograph of an outdoor scene adequately depicts most of the variety in a scene, respondents have similar reactions —in terms of the adjectives they use—to describe both the photograph and the scene. On the other hand, a photograph that shows only a part of a scene's total variation usually accounts for only a portion of the variation in verbal reactions to the entire scene. Therefore, a photograph that shows only part of a scene can change, not only one's word description of the scene, but may also change one's reaction to resource or landscape-management procedures involving the total environment where the photograph was taken.

THE STUDY

Eight different scenes were used in this study. One group of respondents viewed the actual scenes; a second group viewed $5\frac{3}{8}$ x 8 color slide projections of the scenes; and a third group viewed 8 x 10-inch color photos of the scenes. We called these three types of viewing experiences *presentations A*, *B*, and *C* respectively.

Respondents

Three different groups of photography students took part in the study—one group per presentation, selected at random from the undergraduate student body at Syracuse University. Photography students are trained to recognize variations in photographic composition and quality, and we wanted to maximize this possibility in our experiment. We assumed that if a photograph of a scene was not of high professional quality, but respondent reaction was the same for an actual scene and a photograph of that scene, then probably other types of respondents in similar experiments would not be significantly influenced by imperfections in the photographic quality of a scene.

The Measurement Device

In all three presentations, each respondent was asked to look toward the center of a given scene and record his feeling about the scene on each of 27 bi-polar, seven-step adjective scales (figs. 1 to 8).

Social-psychologists refer to these adjective scales as semantic differentials. The 27 adjective scales were selected from previous experiments that used semantic measurements of paintings (*Tucker 1955*), urban environments (*Sanoff 1969*), and unrelated concepts (*Osgood et al 1957*). On the interview forms for the three treatments, the 27 adjective pairs were arranged in a different sequence for each of the 8 scenes. However, the same sequence of adjective pairs was used for the same scene in all three presentations.

The instructions for evaluating each scene in this study followed the procedures outlined by Osgood et al (*1957*). If a respondent felt that a scene was *very closely related* to one end of an adjective scale, he placed a check-mark as follows:

BEAUTIFUL X : _ : _ : _ : _ : _ : _ : **UGLY**

or

BEAUTIFUL _ : _ : _ : _ : _ : _ : X : **UGLY**

If he felt that a scene was *closely related* to one or the other end of the scale (but not extremely), he placed a check-mark as follows:

FRUSTRATING _ : X : _ : _ : _ : _ : _ : **SATISFYING**

or

FRUSTRATING _ : _ : _ : _ : _ : X : _ : **SATISFYING**

If the scene seemed *only slightly related* to one side as opposed to the other side (but not really neutral), the respondent checked as follows:

UNEMOTIONAL _ : _ : X : _ : _ : _ : _ : **EMOTIONAL**

or

UNEMOTIONAL _ : _ : _ : _ : X : _ : _ : **EMOTIONAL**

If a respondent felt that both sides of the scale were *equally associated* with the scene, or that the scale was unrelated to the scene, he placed a check-mark in the middle space:

EXHILARATING _ : _ : _ : X : _ : _ : _ : **DEPRESSING**

Respondents were requested to make a check-mark for each of the 27 adjective pairs as a separate and independent judgment.

Interviews

On-the-scene interviews were conducted at the peak of fall foliage coloration in central New York. Twenty-nine students visited each of the eight sites and were allowed, as a group, to view each scene for about 5 minutes. The total field trip took 3 hours. Forty-four students were used in presentation B, and 30 students in presentation C.

During the on-the-scene interviews, a professional photographer took color slides and color photographs of each scene.

The slides and photographs were used in laboratory presentations B and C, where the viewing time was 1 to 2 minutes for each picture. Each respondent, while viewing each scene, filled out a questionnaire containing the 27 adjective pairs. After all questionnaires were completed, the next scene was presented.

The time lapse between viewing scenes in presentation A was about 15 to 20 minutes. For presentations B and C the time lapse was only a few seconds.

Here is the order in which the eight scenes were viewed:

Scene	*Predominate feature*
1	Syracuse University field house.
2	Part of a car junkyard.
3	A stone-crushing plant.
4	A lake, with the stone-crushing plant in the background.
5	A scenic vista along a rural highway.
6	Railroad tracks and a train station in a rural community.
7	A forest environment: lake with mountains in the background.
8	Waterfall in a forest setting.

Mathematical Analysis

Analyses of the data followed those procedures described by Osgood et al (*1957, pp. 85-90, 99-100*). For the benefit of our readers, we present here the highlights of the analytical procedures we followed.

Each respondent provided a complete set of 27 adjective-pair judgments for each of the 8 scenes. These judgments were converted to a score ranging from 1 to 7, depending on where a respondent placed a check-mark along the 7-point scale of any adjective pair.

Subsequently, the presentation A (or field interview) scores for each scene were factor-analyzed *(Harman 1966)*. Factor-analysis results provided a description of the dimensions of connotative reaction to a given scene—somewhat as independent dimensions of length, width, and height describe the shape of the space within a box.

Osgood et al (*1957*) pointed out that the dimensions, or factors, resulting from factor analysis of semantic differential data define the "semantic space" of the scene; and furthermore, that the distribution of respondents' scores for all adjective-pairs with high factor loadings within a factor represents an independent "cloud of points," or distribution, along that factor.

The objective of the experiment was to determine whether, in terms of semantic differential response patterns, reactions to colored slides and colored pictures of a scene differed significantly from on-site reactions. Therefore, factor analysis of presentation-A data determined which adjective pairs constituted a meaningful cloud of points along each of n independent dimensions, or factors, of semantic space for an actual scene.

Only those factors that accounted for 10 percent or more of the total variation in all adjective-pair scores were considered to be important in defining the semantic space of a given scene. To say it another way, some dimensions of semantic space are more important than others in terms of how well they help to explain the variability of that space. In this case, we were interested only in those dimensions that included 10 percent or more of the total variability in the factor-analysis re-

Table 1.—Number of factors that describe the reaction to presentation A, and the percentage of total variation explained by the factors for each scene

Scene	Number of factors	Percent of total variations explained by all factors
1	8	100
2	4	62
3	6	93
4	5	100
5	4	68
6	4	60
7	4	68
8	3	50
Average	5	75

Table 2.—An example of how data were summarized and compared for each scene

[This analysis is for scene 2, which required 4 independent factors to describe adjective-pair data for that scene. Only those factors that accounted for 10 percent or more of the total variation were considered.]

Presentation	Factors	Number of adjective pairs in the Factor	Percent of total variation described by the factor	Number of respondents by adjective-pair score categories							Presentation comparisons[1]	X^2 value for comparison between presentations
				1.0–1.5	1.6–2.5	2.6–3.5	3.6–4.5	4.6–5.5	5.6–6.5	6.6–7.0		
A	I	7	23	—	1	8	7	11	2	—		
B				1	14	15	10	2	2	—	A vs. B	32.9 *
C				—	3	16	8	2	1	—	A vs. C	18.45*
A	II	6	19	1	—	3	1	7	13	4		
B				—	2	4	14	12	8	4	A vs. B	28.14*
C				—	1	5	5	11	8	—	A vs. C	14.88*
A	III	3	10	3	9	10	6	—	—	1		
B				11	14	14	5	—	—	—	A vs. B	12.22*
C				6	9	12	3	—	—	—	A vs. C	4.65
A	IV	2	10	—	—	7	19	3	—	—		
B				2	4	10	24	3	1	—	A vs. B	3.60
C				3	4	7	13	3	—	—	A vs. C	8.57*
Total	—	13[2]	62	—	—	—	—	—	—	—	—	—

*Indicates presentations differed significantly at 95 percent probability level.

[1]Whenever necessary, contingency-table values were combined in the chi-square analysis so that all cells had expected values of 2 or greater.

[2]Note that the total number of adjectives is less than 27. This is because certain factors that accounted for less than 10 percent of the variation contained the missing adjective-pairs.

sults. Therefore, the variation considered important in the on-site interview data was often less than 100 percent (table 1).

On the average, five independent factors (or dimensions) were required to explain the semantic space of a scene. These five factors accounted for an average 75 percent of the total variation in the semantic-differential response to the scene (table 1). Mathematically, it is possible to define the semantic space of a scene in terms of more than three dimensions (such as an *average* of five independent dimensions in this case), but it is impossible to graphically portray this same space beyond a three-dimensional diagram.

For each scene, chi square (*Walker and Lev 1954*) was used to determine if the distribution of adjective-pair scores along each factor (or cloud of points) in presentation A had the same distribution of scores as the corresponding adjective-pair in presentations B and C (table 2).

Graphic Analysis

Average adjective-pair scores per scene were graphed so that, generally (but not always), a low score represented some degree of dislike, whereas a high score reflected a certain degree of elated feeling about an environment. Graphic results are discussed on a non-statistical basis (figs. 1 to 8).

Table 3.—Percent of presentation A variation that was explained by presentations B and C

Scene	Treatment B (Color slides)	Treatment C (Color pictures)
1	76	53
2	16[1]	16
3	32	11
4	64	12
5	48	33
6	41	100
7	100	54
8	28	28
Average	51	38

[1]For example, presentation B explained 16 percent of the variation that occurred in the on-site interviews at scene 2. This percentage value was obtained by first summing values of column 4 in table 2 whenever presentation-A and presentation-B data were not significantly different. In this case, they were similar only in factor 4; so the sum value was 10 percent. Next, this sum divided by the proportion of total variation described by all factors equals 16 percent: $10/62 = 16\%$.

Why did we conduct both a mathematical and a graphic analysis of the data? Social-psychologists have not yet defined what constitutes a *meaningful* statistical difference between sets of semantic differential data. So, what may be statistically significant in this study may not necessarily be managerially significant to the practitioner who wants to use the study results. Graphic presentations of results, therefore, permit the reader to decide for himself whether presentations B and C differ from presentation A for his particular situation or objective in the use of photographs.

RESULTS

Reaction patterns of color slides and pictures accounted for 11 to 100 percent of the on-site presentation variation (table 3). On the average, a color-slide presentation of a scene described 51 percent of the on-site response variation, and a color picture described 38 percent. These average percentages, however, do not reflect the range in results.

In five of the eight scenes (1, 3, 5, and 7), color-slide projections described more presentation-A response variation than color pictures did. In two of the scenes (2 and 8), color-slide and photo results were about the same. Only for scene 6 did the photo measure more presentation-A variation than the slide (table 3).

When looking at the results of the statistical and graphic analyses, one cannot assume that plotted mean values are not equal simply because they do not seem to belong to the same distribution and vice versa. For example, the color picture for scene 6 accounts for 100 percent of the variation in the on-the-scene response to presentation A (table 3), but the graphic means for response data do not overlap exactly for presentations A and C (fig. 6).

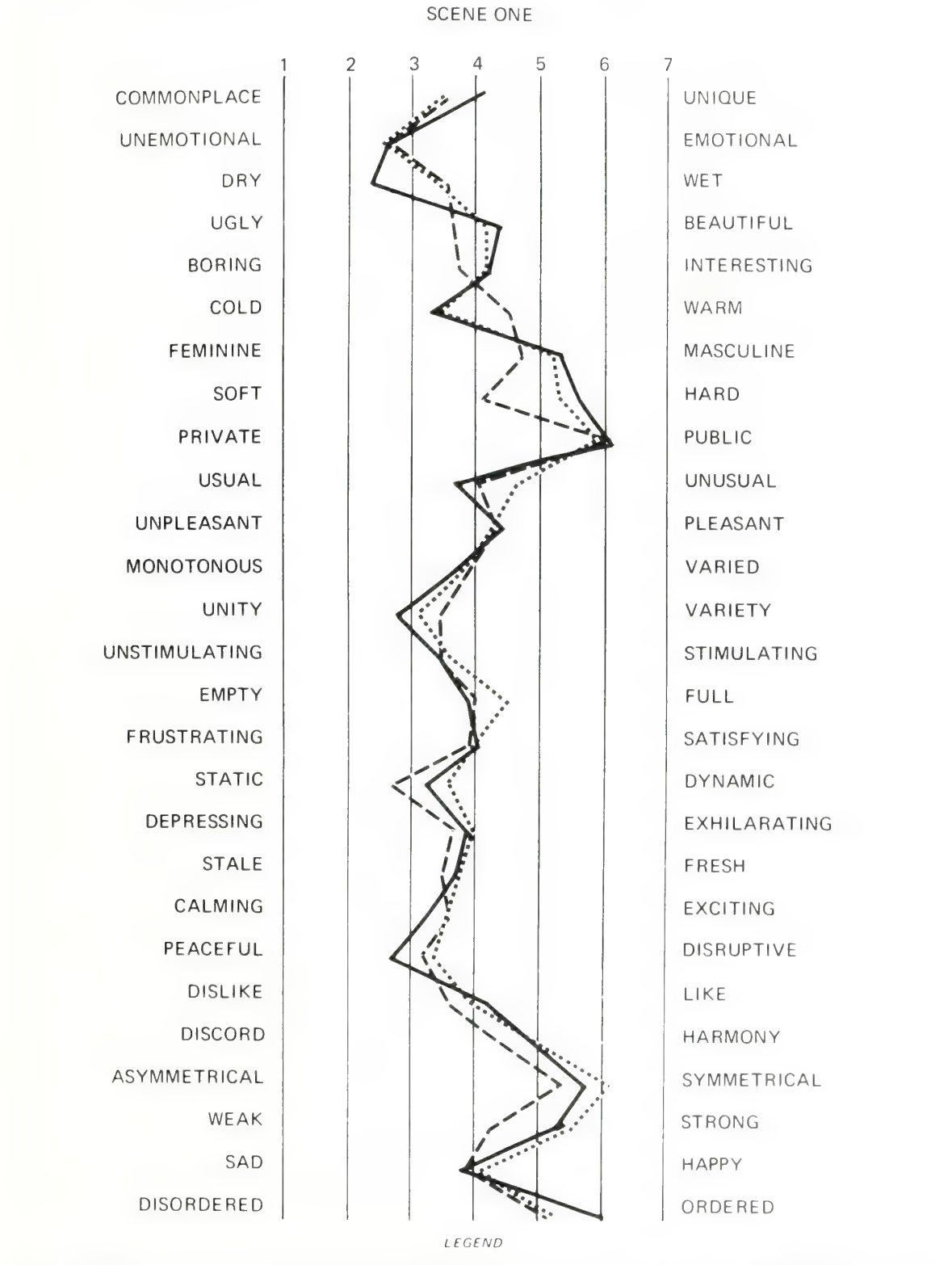
The results of this study are limited to a specific population, time period, and set of environments. The experiment was conducted under controlled conditions that may not exist when people view scenes.

The average person probably will want to spend more time in an environment he enjoys (the waterfall in scene 8, for instance) than in one he dislikes (such as the junkyard in scene

TEXT CONTINUES ON PAGE 23.

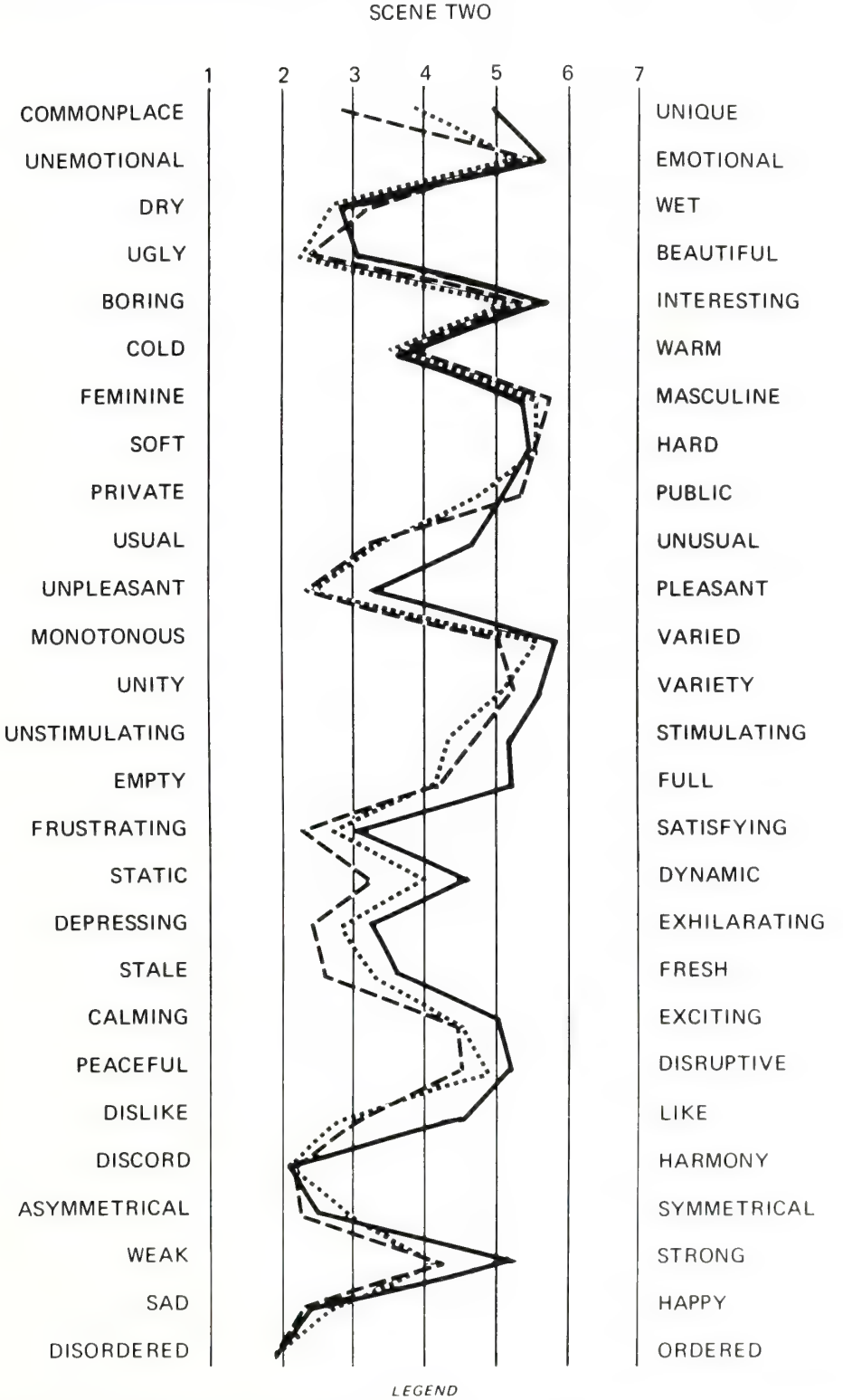
Scene 1.—A circular-shaped college field house.

Figure 1.—Statistical mean distribution of semantic differential scores for the three presentations of scene 1.



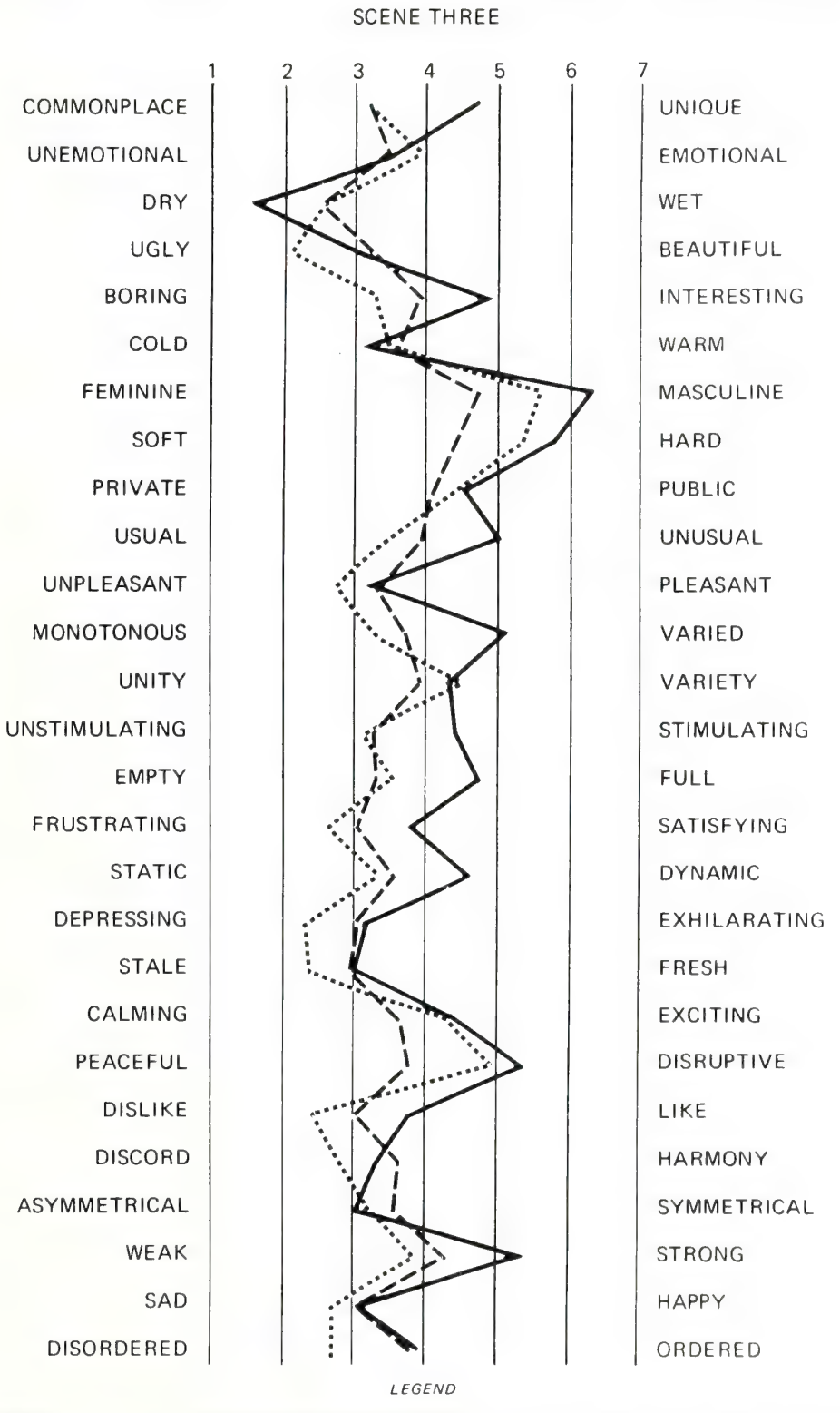
Scene 2.—Part of a car junkyard.

Figure 2.—Statistical mean distribution of semantic differential scores for the three presentations of scene 2.



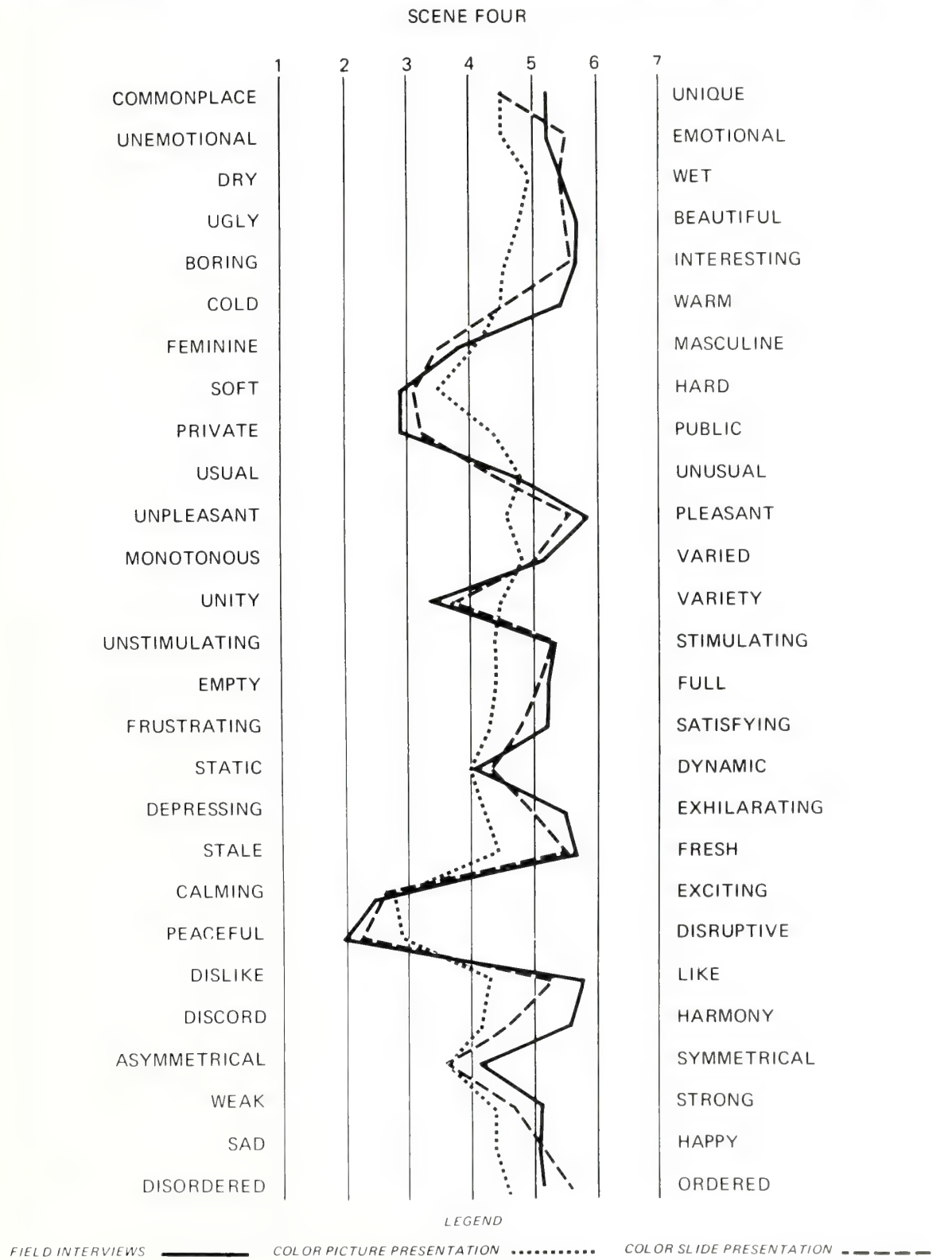
Scene 3.—A stone-crushing plant.

Figure 3.—Statistical mean distribution of semantic differential scores for the three presentations of scene 3.



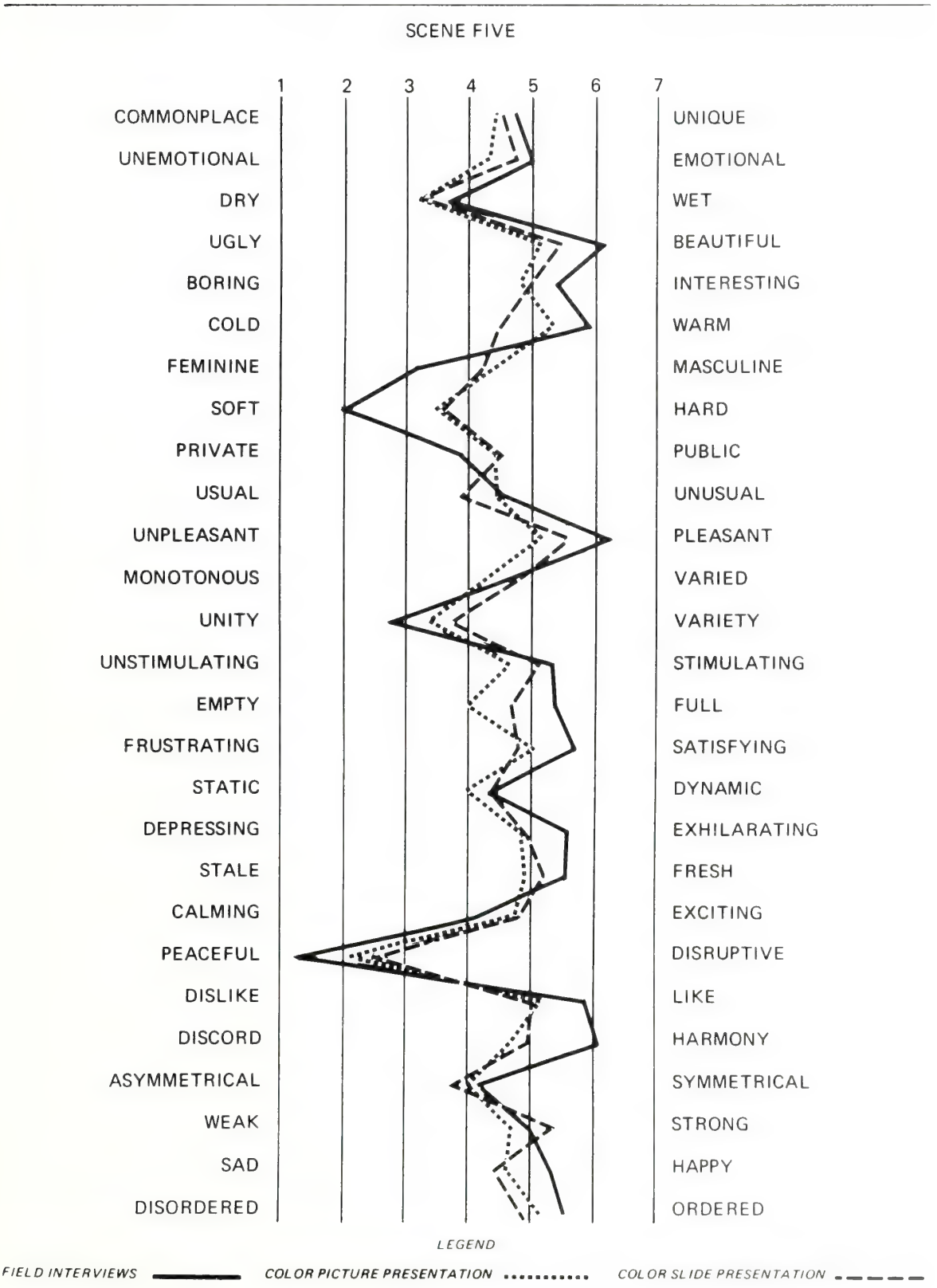
Scene 4.—A lake with stone-crushing plant from scene 3 appearing in the background

Figure 4.—Statistical mean distribution of semantic differential scores for the three presentations of scene 4.



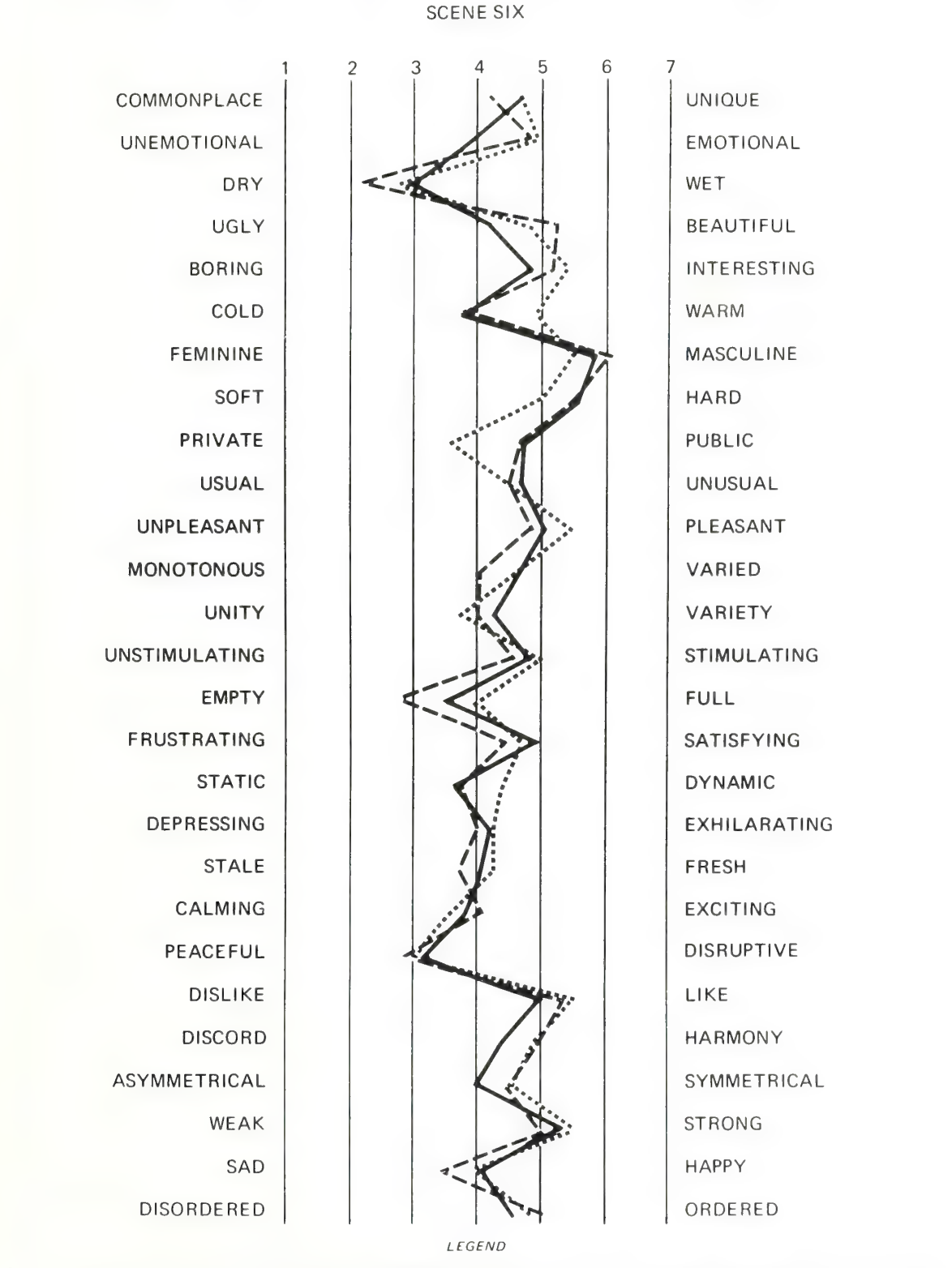
Scene 5.—A vista along a rural highway.

Figure 5.—Statistical mean distribution of semantic differential scores for the three presentations of scene 5.



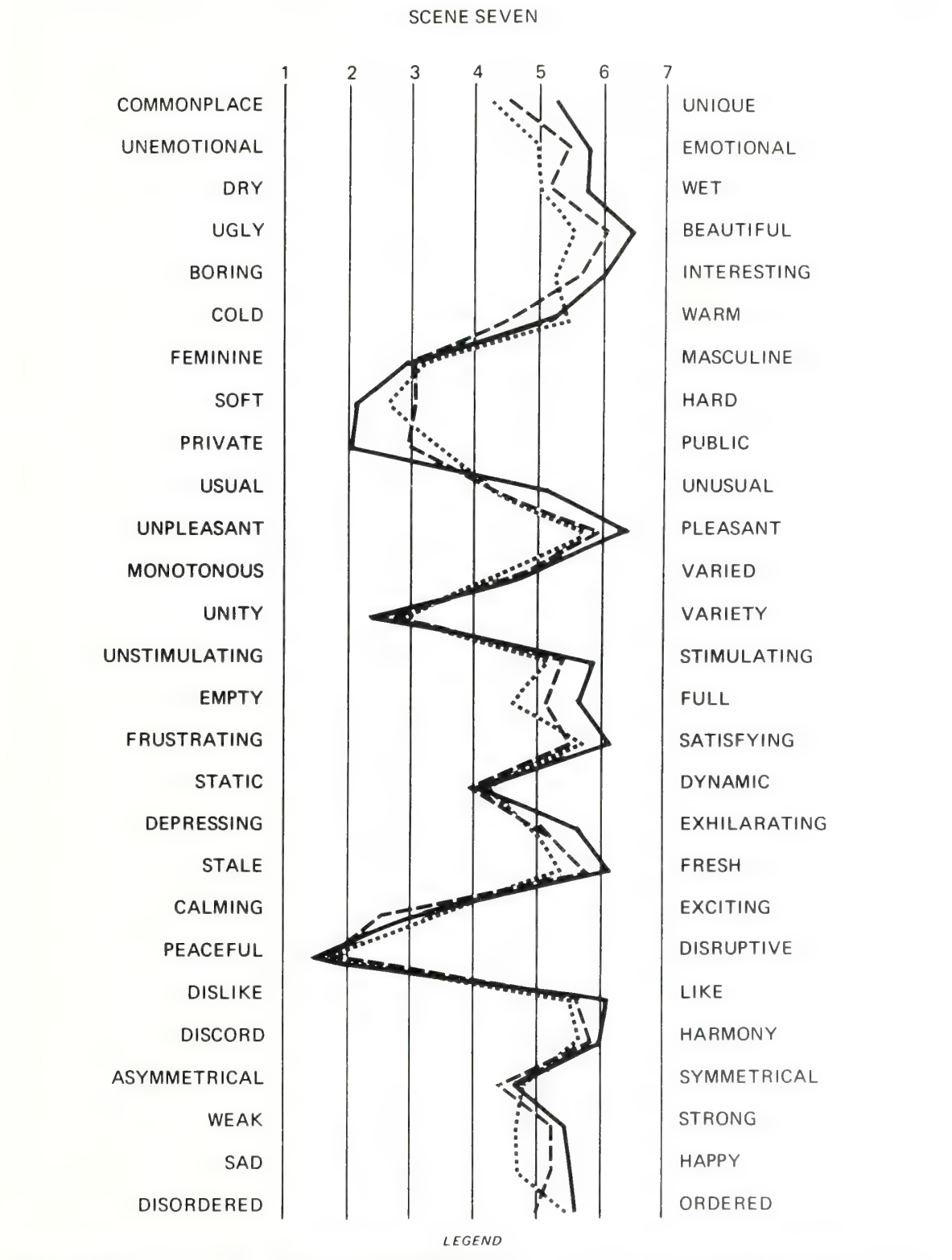
Scene 6.—Railroad tracks and train station in rural community.

Figure 6.—Statistical mean distribution of semantic differential scores for the three presentations of scene 6.



Scene 7.—A forest environment and lake, with mountain in back-

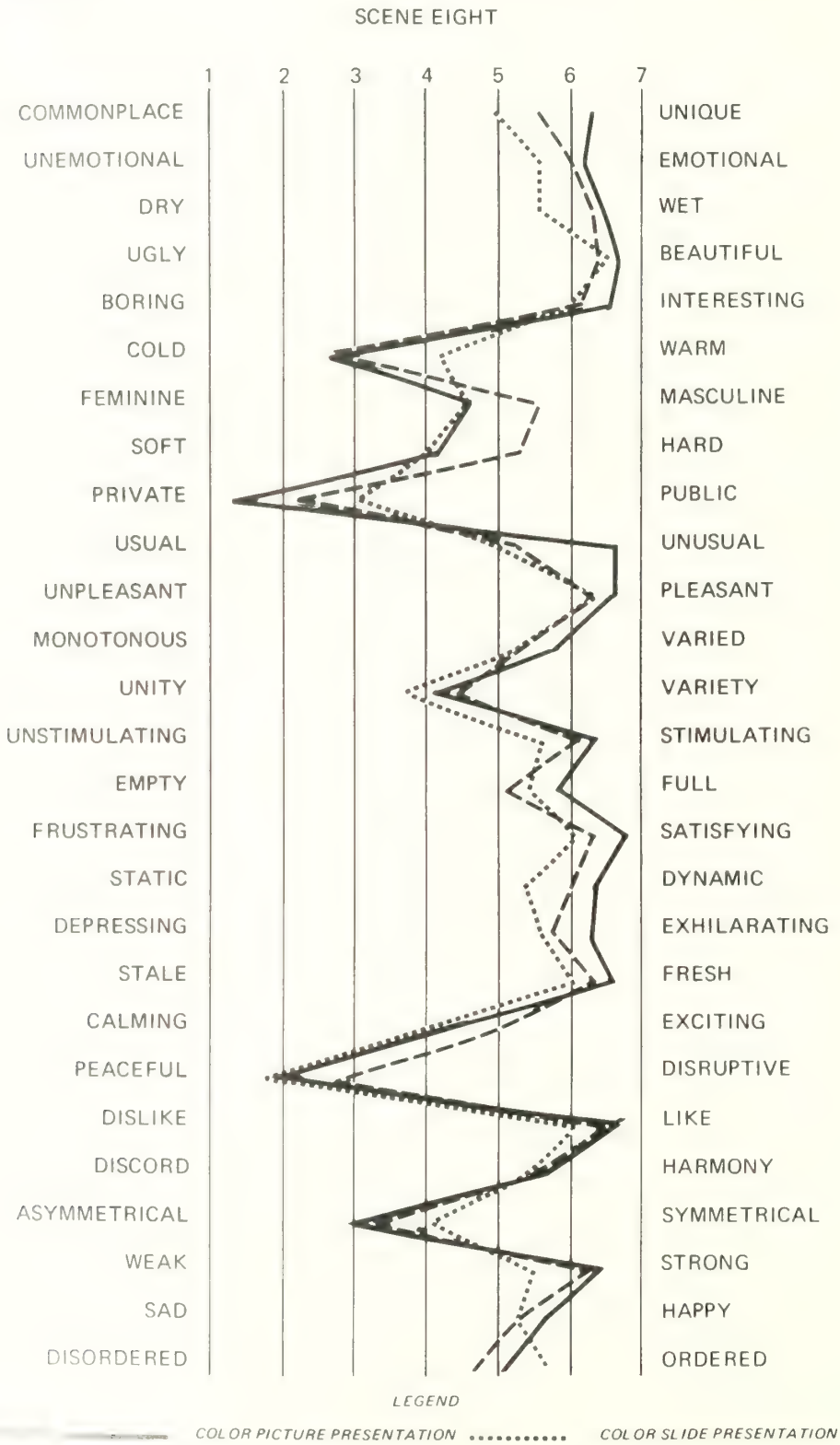
Figure 7.—Statistical mean distribution of semantic differential scores for the three presentations of scene 7.



Scene 8.—A waterfall in a forest setting. A, the full scene viewed in presentation A; the area marked off at upper left was used in presentations B and C. B, the photo used in presentations B and C.

B

Figure 8.—Statistical mean distribution of semantic differential scores for the three presentations of scene 8.



2). This type of behavior pattern was very evident in the field interviews. Consequently, the reasons why one views a given scene and the length of time he spends in that environment probably condition his reaction to the scene. In this experiment we did not try to account for this possibility.

Most of the students had seen many of the scenes several times before. Therefore the adjective-description patterns for each of the more familiar scenes may typify the reaction that could be expected across a range of similar environments.

Essentially, each scene constitutes a separate experiment involving respondent reaction to that scene. On the other hand, hypotheses suggested by interview results from one scene occasionally were reinforced by interview results from a later scene. We did not attempt to relate viewer reactions among scenes, although the order of presentation may have affected viewer reactions to succeeding scenes.

Scene 1 (Field house)

In the field interviews, respondents stood in a tree-shaded location and looked out into a bright sunny scene. This situation was similar to the laboratory environment for the color-slide presentation and therefore may help account for the 76 percent of field-interview response explained by the color-slide projection. In comparison, response patterns to the color-picture presentation explained 53 percent of presentation-A variation.

In the graphic analysis of the data for this scene, the average value for most adjective-pairs did not vary by more than one scale point between presentation A and the other two presentations (fig. 1). Therefore, on a non-statistical basis, the average responses to all three presentations were fairly similar.

As might be expected, the meaning of this scene was closely related to the adjectives *public*, *symmetrical*, and *ordered*; and only slightly related to the adjective *dry*. Otherwise, average scores for all other adjective pairs ranged between scores 3 and 5—that is, one of the two adjectives in a pair was only slightly related, was not associated, or was only slightly unrelated to the meaning of the scene.

On the basis of these results, we suggest the following hypothesis for further testing:

> Color slides and possibly color pictures that adequately show a single architectural structure and one center of interest in an uncluttered environment may induce word responses that are similar to on-site viewing reactions.

In a sense, landscape architects assume that at least part of this hypothesis is operating whenever they present a model or a drawing of a proposed project to a client.

Scene 2 (Junkyard)

Treatments B and C accounted for only 16 and 17 percent, respectively, of on-site verbal-response variation.

During the field interviews, the students stood on gray-colored gravel within this disorganized environment as car traffic moved along a road in the center of the scene.

Graphically, the adjective-air scores for presentations B and C were parallel, but were usually 1 to 1.5 points lower than presentation-A data about two-thirds of the time. For example, in terms of the adjective-pairs that were used, the picture and color-slide scores were not as *stimulating*, *exciting*, or *strong* as the on-site feeling about this environment. On the other hand, respondents felt that presentations B and C were more *unpleasant*, *frustrating*, and *depressing* than the actual scene.

The similarity in average response patterns among the three presentations for scene 2 suggests that slides and photographs could come reasonably close (on a nonstatistical basis) to duplicating on-site feeling for this kind of scene (fig. 2).

Analytical results and comments by respondents in all three presentations for this scene suggested that:

> Photographic presentations of polluted or unpleasant natural environments elicit a greater degree of unfavorable reactions than those reactions obtained at the actual site, unless the photo presents most of the environment's variation and is supplemented by sensory stimuli of sound and smell. However, there may be a high positive correlation between reaction to photographic presentations and on-site reaction to this type of scene.

Scene 3
(Stone-Crushing Plant)

The color slide presentation explained 32 percent of presentation-A verbal-pattern responses, and color photos explained 11 percent.

In the field tests, human activity and structures on both sides and behind the test area seemed to distract respondents.

Overall results tended to support our previous hypothesis for scene 2 about the need for total photo coverage of visually polluted environments before one can duplicate on-site reaction or feeling for that environment. Average semantic differential scores usually ranged within one plus or minus point of the neutral zone, with only a few exceptions for on-site reactions such as the adjectives *dry* and *masculine*.

Scene 4
(Lake and Stone-Crushing Plant)

Presentation-A respondents viewed this scene from within the cool shadowed protection of a rustic open-air shelter in a picnic area. This viewing situation was somewhat similar to the slide presentation in the laboratory for this scene, which may account partially for the better performance of the slide (64 percent) over the photo (12 percent) in duplicating the on-site response variation in presentation A.

In the graphic analysis, response patterns for presentations A and B were similar, but those for A and C were quite different (fig. 4).

There was a dramatic shift in favorable reaction toward the total environment when the pollution that was shown in scene 3 was followed by the mountains and water in scene 4. For example, adjective scores for *beautiful*, *interesting*, *pleasant*, and *peaceful* were either neutral or negative for scene 3, but quite positive for scene 4. These results suggest that:

> In terms of viewer response, natural environments can be used effectively to subordinate the negative effects of nearby, familiar, visual, and biological pollution.

An additional hypothesis suggested by semantic differential results from scene 4 corresponds to the hypothesis suggested for scene 1:

> Color slides that adequately portray most of the variation of an outdoor environment may be adequate for measuring response to the actual scene. This may be true even when a small degree of visual pollution exists in the scene.

Scene 5
(Roadside Scenic Vista)

The slide and photo were restricted to about 50 percent of the total variation in the scene. Furthermore, the two-dimensional aspect of presentations B and C accentuated a highway guard rail that was subordinate in the actual scene.

Respondents stood in the open along a highway overlooking this scene during the on-site evaluations. The 48 and 33 percent of on-site variation described respectively by the slides and photo enforced the need to have complete photo coverage of a natural scene when measuring reaction to the scene. The graphed viewer-response of all three treatments tended to highlight the reaction differences between presentation A and the other two. Results of average on-site reactions indicated that the actual scene was especially more *beautiful*, *warm*, *soft*, *pleasant*, *peaceful*, and *harmonious* than colored pictures or slides of the scene (fig. 5).

Scene 6
(Railroad Tracks and Station)

The color photo explained 100 percent of on-site reaction. The color-slide treatment was less than half as effective, accounting for only 41 percent.

The color print had a slightly lower camera angle than the slide. Perhaps the difference in results between the photo and the slide presentation was caused by a difference in camera angle; but this aspect of the problem needs additional research.

Graphic presentation of average user response to all three treatments showed how presentation A and C data tended to follow the same pattern (fig. 6), thus reinforcing the statistical analysis results.

The railroad—a theme that pervaded and glorified the technological revolution in this country—was accentuated by including an abandoned but well-preserved railroad station. In its heyday, this environment was domi-

nated by noise and smoke similar to that dominating scene 3. Why, then, didn't scene 6 (fig. 6) and scene 3 (fig. 3) have similar semantic differential response patterns? Even more intriguing is the question, Why didn't respondents appreciate scene 6 more than scene 1, which was a modern non-polluting structure? In answer to these questions we suggest that:

> In many respects, on-site and photographic presentations of scenes of historical technological achievements may elicit more overall interest and appreciation than modern non-polluting man-made structures.

Such hypotheses lead credence to the need for preserving (on-site and in photographs) past historical developments. Such developments may be regarded by today's observers as particularly *masculine*, *beautiful*, *peaceful*, *likeable*, and *strong* (fig. 6).

Scene 7 (Lake and Mountain)

The foreground objects appeared taller than they really were because of a low camera angle in the photo. Although the representation of the environment does not include the entire scene, the variability in the remainder of the scene did not differ much from that shown in the picture. The students stood in an isolated area along a grass-covered shore of the lake as they recorded how they felt about this scene.

Survey results from this scene supported the hypothesis generated by results from scene 4, suggesting that photo presentations of natural environments, adequately portraying most of the variation in a natural environment, can be used to measure feeling about that environment. The color slide for scene 7 accounted for 100 percent of presentation-A variation; the photo print explained 54 percent. Part of the difference between slide and print results may be due to the total in-depth focus of the slide.

Graphic analysis of the data reinforced the similarities between results of presentations A and B (fig. 7.) Most of the time, presentation-C results also closely paralleled the on-site results.

Note that as we shifted from environments containing man-made structures—buildings junkyards, factories, and roads (scenes 1 to 6)—to natural environments—vegetation, mountains, and lakes (scene 7)—the *meaning* of the environment to the observer became more accentuated.

For example, scene 7 elicited a much more *beautiful*, *fresh*, *unifying*, *pleasant*, *peaceful*, *likeable*, and *harmonious* feeling than most of the other scenes. Therefore our experimental results supported the accepted fact that:

> Generally, natural environments are more pleasing to man than environments containing man-made structures and developments.

Scene 8 (Waterfall)

Content of the slide and print was the same, but purposely included only about 30 percent of the total variation of the actual waterfall; about 60 percent of the waterfall was not shown on the slide or the color print.

The slide and the photo each accounted for 28 percent of presentation-A response variation. Because of the close agreement between the portion of total waterfall variation included in presentations B and C, and the amount of variation in on-site feeling explained by these presentations, we propose one final hypothesis for further testing:

> A viewer's response to an actual scene probably is governed by his feeling toward the total variation in patterns and colors in that scene. Therefore the amount of on-site variation in the response patterns that can be duplicated by a photographic presentation of a scene probably is conditioned by the amount of actual total environmental variation represented in the colored photo or slide.

However, graphic analysis of the data suggested that the photographic presentations did a better job of duplicating on-site reaction than the statistical analysis seemed to indicate.

Only rarely did the average values for the two photo presentations vary by more than $\pm$ 1 from average values from the actual situation. Here again, a graphic analysis of the data indicated that all three presentations had similar responses (fig. 8).

Graphic results for this scene substantiate, even further, the conclusions suggested from

results of scene 7: that the more intriguing a natural environment is, the more positive the response—in terms of observer reaction—to that environment.

CONCLUSIONS

Overall, our research results suggested that, when color-slide or picture presentations adequately depict most of the variation of natural and man-made environments, the adjective-pair measurement of response to the picture presentations agrees favorably with similarly measured on-site responses to the same scenes.

At the same time, experimental results also suggest that if pictorial presentations include only a portion of the total variation in natural environments, man-made structures, or polluted scenes, responses to such presentations are significantly different from on-site response patterns to the same conditions.

Study results also have particular relevance to previous research in which photographs were used to measure people's reactions to their environment and to relate that reaction in mathematical terms to various elements in those same environments *(Shafer et al 1969)*.

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Shafer, Elwood L., Jr., and Thomas A. Richards.
1974. **A comparison of viewer reactions to outdoor scenes and photographs of those scenes.** NE. Forest Exp. Sta., Upper Darby, Pa.
26 p., illus. (USDA Forest Serv. Res. Pap. NE-302)

A color-slide projection or photograph can be used to determine reactions to an actual scene if the presentation adequately includes most of the elements in the scene. Eight kinds of scenes were subjected to three different types of presentation: (A) viewing the actual scenes, (B) viewing color slides of the scenes, and (C) viewing color photographs of the scenes. For each scene, responses to each of the three treatments were compared statistically and graphically.

907.1

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Response to

CROP-TREE RELEASE

by 7-year-old stems of Red Maple Stump Sprouts and Northern Red Oak Advance Reproduction

by G. R. Trimble, Jr.

USDA FOREST SERVICE RESEARCH PAPER NE-303
1974

NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082
F. BRYAN CLARK, STATION DIRECTOR

ABSTRACT

This paper deals with crop-tree release of two species typical of a fair site: red maple stump sprouts and northern red oak advance reproduction. A study was made to test the feasibility of doing a crop-tree release immediately after the canopy closed and crown classes could be distinguished. The study was made in a 7-year-old even-aged hardwood stand on the Fernow Experimental Forest near Parsons, West Virginia.

A comparison of the following variables was made between released and control trees: total height growth, dbh growth, length of clear stem, and change in crown class. For the red maple sprouts, two crown classes were studied: dominants and codominants. For the red oak, three crown classes were studied: dominants, codominants, and intermediates. After the initial measurements, repeat measurements were made at 2 and 5 years following treatment.

We conclude from this study that for the type of release, species, and site studied, release had no significant effect on height growth.

The data indicate that diameter growth was favorably affected by release of the red maple stump sprouts, but release had no significant effect on the diameter growth of red oak advance reproduction.

Length of clear stem was retarded during the 5-year period by release, but during this period red oak cleared up at a faster rate than red maple.

Changes in 5-year crown class indicate that release had a minor effect on red oak, where crowns retrogressed heavily in dominance in both the release and control categories. However, released red maple codominants were definitely more dominant than controls 5 years after release.

Mortality was slight in all of the stem categories.

THE AUTHOR

GEORGE R. TRIMBLE, JR., now retired, was timber management project leader for the USDA Forest Service's Northeastern Forest Experiment Station at its Timber and Watershed Laboratory at Parsons, West Virginia. He received his forestry training at the University of Maine. He worked for a number of years in watershed-management research both in West Virginia and New Hampshire, and has worked on forest-management problems in most of the northeastern states.

MANUSCRIPT RECEIVED FOR PUBLICATION 13 MARCH 1974

INTRODUCTION

THIS IS A COMPANION paper to Research Paper NE-253 "Response to crop-tree release by 7-year-old stems of yellow-poplar and black cherry" (*Trimble 1973*). The earlier paper dealt with the response of two typically desirable species that usually follow clearcutting on an excellent site, while this paper deals with two species typical of a fair site. Although the studies were carried out in the same way on both areas, site quality and species were different. The organization of this paper is similar to that of the previous one to facilitate comparisons of results.

The objective of this study was to test the feasibility of making a crop-tree release as soon as crop trees could be selected—immediately after the canopy closed and crown classes could be distinguished. The purpose of making the operation so early was to enhance the possibility of improving species composition. A crop-tree release was used rather than an area-wide thinning because releasing individual trees is much less expensive; and when interest rates are considered, the carrying charge for work done early in the life of a stand mounts high. Each dollar spent in a stand at 7 years of age, if carried at 6 percent interest to the end of the rotation at 80 years, would have to result in an increase of harvest returns of $70 just to break even. However, in a managed stand, some of the effects of precommercial operations would be realized sooner in commercial thinnings. And if such operations increased growth rates they would result in shortened rotations.

To measure the biological response to the release, a number of variables were examined in detail. More data are needed before detailed guidelines can be developed for operations of this kind—or even before a good case can be made that precommercial operations are financially feasible.

DESCRIPTION OF THE AREA

The study locale was the Fernow Experimental Forest near Parsons, West Virginia. Site quality was fair: about site index 60 for oak. The soil was a well-drained Calvin channery silt loam derived from sandstone and shale. Elevation of the study area was 2,300 feet, and slope averaged about 25 percent. Annual rainfall was about 59 inches and was well distributed throughout the year. The frost-free growing season was about 4½ months.

The 7-year-old stand developed as a result of clearcutting a 55-year-old, well-stocked, unmanaged stand that contained a number of old residuals from the previous harvest. For sawlog management the second-growth trees were too young for clearcutting. This stand contained a wide variety of species, such as red maple (*Acer rubrum* L.), the upland oaks (*Quercus* L.), blackgum (*Nyssa sylvatica* Marsh.), sourwood (Oxy*dendrum arboreum* (L.) DC.) and other typical dry site species. The research clearcut produced 6,547 board feet of sawlogs and 14 cords of pulpwood per acre. All 1- to 5-inch stems left standing were treated with a basal spray of 2,4,5-T in oil and most of them died (*Trimble and Wendel 1966*).

STUDY METHODS

Two species were studied: red maple stump sprouts and northern red oak (*Q. rubra* L.) seedlings and seedling sprouts. The red oaks were advance reproduction. Of the red maple sprouts, two crown classes were studied: dominants and codominants. Of the red oak, three crown classes were studied: dominants, codominants, and intermediates. The number of released and control trees were as follows:

Species and initial crown dominance class	*No. of released stems*	*No. of control stems*
Red maple sprouts		
Dominant (40 stems)	20	20
Codominant (39 stems)	20	19
Red oak advance reproduction		
Dominant (20 stems)	10	10
Codominant (40 stems)	20	20
Intermediates (39 stems)	19	20

We had intended to sample 20 trees in each of three crown classes but were unable to find suitable intermediate red maple sprouts; we were also unable to find 20 dominant red oaks.

The sample trees were permanently numbered in the 7-year-old hardwood stand. The following measurements were taken on each of them: total height, dbh, and length of clear stem. Measurements were repeated after two and five growing seasons. At each repeat measurement, crown positions were reclassified.

After the initial crown classification and stem measurements were made, the crop trees designated for treatment were released by removing from within a 5-foot radius all stems that were over half as tall as the crop tree (*Trimble 1971*). Grapevines growing in the treated crop trees were severed. This operation left all released trees in a dominant crown position, including those that had originally been intermediate.

RESULTS

Effect on Height

When the data were analyzed for the 5 years after treatment, they indicated that the height growth of released trees did not differ significantly (at the 5-percent level) from the height growth of the control stems (table 1). This was true for both red maple and red oak and for all crown classes.

However, when we look at the data for the 2-year period and the following 3-year period

Table 1.—Average total heights and average height-growth rates for released and unreleased stems

Crown class before treatment	Treatment	Sample trees[a]	Average height[b]			Average height growth		
			At 7 years	At 9 years	At 12 years	7 to 9 years annual	9 to 12 years annual	7 to 12 years annual
		No.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
		RED MAPLE STUMP SPROUTS						
Dominant	Release	20	16.2	22.7	28.8	3.05	2.03	2.44
Dominant	Control	20	16.2	22.1	28.5	2.95	2.13	2.46
Codominant	Release	19	14.7	20.4	26.0	2.85	1.87	2.26
Codominant	Control	18	13.7	19.2	24.9	2.75	1.90	2.24
		RED OAK ADVANCE REPRODUCTION						
Dominant	Release	10	11.6	15.4	22.7	1.90	2.43	2.22
Dominant	Control	10	12.1	16.3	23.2	2.10	2.30	2.22
Codominant	Release	20	9.2	12.3	18.2	1.55	1.97	1.80
Codominant	Control	20	9.4	12.6	18.3	1.60	1.90	1.78
Intermediate	Release	19	7.5	9.9	13.2	1.20	1.10	1.14
Intermediate	Control	19	7.7	10.3	12.8	1.30	.83	1.02

[a] Total number of sample trees alive 5 years after release.
[b] Based on number of sample trees alive after 5 years.

Table 2.—Average dbh and average dbh growth rates for released and unreleased trees

Crown class before treatment	Treatment	Sample trees[a]	Average dbh[b]			Average dbh growth		
			At 7 years	At 9 years	At 12 years	7 to 9 years annual	9 to 12 years annual	7 to 12 years annual
		No.	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
RED MAPLE STUMP SPROUTS								
Dominant	Release	20	1.5	2.4	3.4	0.45	0.33	0.38
Dominant	Control	20	1.5	2.0	2.8	.25	.27	.26
Codominant	Release	19	1.2	2.0	2.9	.40	.30	.34
Codominant	Control	18	1.0	1.4	1.9	.20	.17	.18
RED OAK ADVANCE REPRODUCTION								
Dominant	Release	10	0.9	1.3	2.0	0.20	0.23	0.22
Dominant	Control	10	.9	1.3	1.8	.20	.17	.18
Codominant	Release	20	.6	1.0	1.5	.20	.17	.18
Codominant	Control	20	.6	.9	1.4	.15	.17	.16
Intermediate	Release	19	.4	.6	.9	.10	.10	.10
Intermediate	Control	19	.5	.6	.8	.05	.07	.06

[a] Total number of sample trees alive 5 years after release.
[b] Based on number of sample trees alive after 5 years.

separately, a different picture emerges. *For the red oak*, for the 2-year period after release (7 to 9 years), released stems of all crown classes grew slightly slower than the control stems. For the following 3-year period, the situation was reversed; released stems of all crown classes grew slightly faster than the control stems. The height-growth relationship to release for the two periods was the same as we found for yellow-poplar (*Liriodendron tulipifera* L.) and black cherry (*Prunus serotina* Ehrh.) on the better site. The height growth of *red maple stump sprouts* for the two periods was the opposite of that found for red oak advance reproduction: released stems grew slightly faster during the first part of the 5-year period and control stems grew faster during the last 3 years of the period.

None of the differences between growth rates of the released stems and those of the control stems was statistically significant (at the 5-percent level). However, the consistent direction of the differences within species suggests that there are real differences in growth between released and control stems.

Another height-growth relationship for both released and control stems shows up in the data. For the first 2 years, red maple sprouts grew faster than red oak in both dominant and codominant crown classes; for the last 3 years, dominant red oak grew faster than dominant red maple and the growth of codominants was about the same for both species. It appears that the faster height growth rate of red maple stump sprouts over red oak (seedlings and seedling sprouts combined) lasted about 8 to 10 years after clearcutting.

Effect on Diameter

For the 5-year period, released red maple stump sprouts grew significantly (5-percent level) faster in diameter than control stems in both the dominant and codominant classes (table 2). Differences were greater for the codominant than for the dominant stems. The trend of differences was the same for both the first 2 years and the last 3 years.

For the red oak trees, only the intermediate stems showed significantly greater growth in dbh of the released stems.

Like height growth, diameter growth was greater for the more dominant crown classes. Unlike the height-growth relationship, however, where red oak caught up with red maple when the trees were between 8 and 10 years old, diameter growth of the red maple exceeded that of red oak until the end of the study period.

Effect on Length of Clear Stem

Release retarded natural pruning for all crown classes of both species throughout the 5-year period of study (table 3). The differences (as percentages) were greater for red maple than for red oak.

At the beginning of the study period, and before any trees were released at 7 years, comparable crown classes of both species had about the same length of clear stems; but 5 years later, after release, both control and released trees of red oak had greater clear lengths. This indicates that at somewhere around 7 years of age stems of red oak advance reproduction begin to clear up faster than red maple stump sprouts.

Effect on Dominance Classification

Crown classes were determined before release, and all released trees were left in a dominant position. The control (unreleased) trees were left in their original crown position. At 5 years, all sample trees were again classified as to their crown positions (table 4). The changes over this 5-year period lead to the following conclusions:

For both species, many trees of most crown classes retrogressed in dominance. Retrogression was greater with oak than it was with red maple, and it was greater with the lower crown classes (as determined on the original stems). Also, more of the released stems than of the controls retained their original crown position, except for the intermediate red oak, where both released and control stems were dropping rapidly behind.

Many of the red oak dominants were, after 5 years, still in good position even though they had lost some dominance: 80 percent of the released stems were still dominant or codominant as were 70 percent of the controls. Red maple had held its crown position better: of the dominant stems, 95 percent of both released and control dominants were still dominant or codominant. And release had had a definitely favorable effect on codominant red maple stems; 85 percent of them were still dominant or codominant as contrasted with only 32 percent of the controls.

In general, after 5 years the effects of release on crown position were appreciable for red maple stump sprouts, both original dominants and codominants. For red oak, however, release had had less effect.

Table 3.—Average length of clear stem and average clear-stem increase for released and unreleased trees

Crown class before treatment	Treatment	Sample trees[a]	Average length of clear stems[b]			Average clear stem increase		
			At 7 years	At 9 years	At 12 years	7 to 9 years annual	9 to 12 years annual	7 to 12 years annual
		No.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
		RED MAPLE STUMP SPROUTS						
Dominant	Release	20	3.1	3.2	4.5	0.05	0.43	0.28
Dominant	Control	20	3.0	4.0	7.9	.50	1.30	.98
Codominant	Release	19	2.9	3.3	4.4	.20	.37	.30
Codominant	Control	18	2.9	4.3	8.0	.70	1.23	1.02
		RED OAK ADVANCE REPRODUCTION						
Dominant	Release	10	3.0	3.4	7.0	0.20	1.20	0.80
Dominant	Control	10	3.0	5.9	11.8	1.45	1.97	1.76
Codominant	Release	20	2.5	3.4	7.5	.45	1.37	1.00
Codominant	Control	20	2.5	3.5	8.0	.50	1.50	1.10
Intermediate	Release	19	2.9	3.8	6.0	.45	.73	.62
Intermediate	Control	19	2.6	4.1	6.6	.75	.83	.80

[a] Total number of sample trees alive 5 years after release.
[b] Based on number of sample trees alive after 5 years.

Table 4.—Five-year change in crown class

Crown class before treatment	Treatment	Crown class 5 years later								Dead		Dead and overtopped
		Dominant		Co-dominant		Intermediate		Overtopped				
		No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.	Pct.
		RED MAPLE STUMP SPROUTS										
Dominant	Release	17	85	2	10	1	5	0	0	0	0	0
Dominant	Control	3	15	16	80	1	5	0	0	0	0	0
Codominant	Release	9	45	8	40	1	5	1	5	1	5	10
Codominant	Control	1	5	5	27	9	47	3	16	1	5	21
		RED OAK ADVANCE REPRODUCTION										
Dominant	Release	2	20	6	60	2	20	0	0	0	0	0
Dominant	Control	0	0	7	70	3	30	0	0	0	0	0
Codominant	Release	1	5	6	30	11	55	2	10	0	0	10
Codominant	Control	0	0	6	30	10	50	4	20	0	0	20
Intermediate	Release	0	0	1	5	6	32	12	63	0	0	63
Intermediate	Control	0	0	1	5	5	25	13	65	1	5	70

Effect on Mortality

Of the 178 trees in the original samples, only three died during the 5-year period (table 4). Thus the mortality has been very low, and from the looks of the stand it will not increase markedly in the near future, except for the intermediate red oak. This is somewhat in contrast to our study of yellow-poplar and black cherry on an excellent site where 5-year mortality was heavy among intermediates and even codominants, especially the controls. Several conditions probably account for this difference: (1) the canopy is naturally denser on the better site, (2) a heavy stand of American chestnut sprouts is dying and opening up the canopy on the poor site, (3) a lower percentage of sample trees were in the intermediate class on the poorer site (no red maples below codominant position were studied), (4) red oak and red maple, especially the latter, are more tolerant of shade than yellow-poplar and black cherry, and (5) young stump sprouts—in the case of red maple—outgrow young seedlings, and the stems of yellow-poplar and black cherry studied were seedlings (or in some cases of the latter, small seedling sprouts).

Effect on Grapevines

On the better sites grapevines were found to be highly damaging to young stems after clearcutting, but we found them to be of no importance on this fair site. When the crop trees were selected in 1968, we found grapevines growing in only three trees. All of these were control dominant red maple sprouts and the vines were not cut. Five years later, only two of these trees had grapevines in them, and the vines were doing no damage. No new vines had grown into other trees.

This information substantiates our general observation that grapevines are primarily a pest on better sites.

CONCLUSIONS AND DISCUSSION

We conclude from this study that for the type of release, species, and site studied, release had no significant effect on height growth.

The data indicate that diameter growth was favorably affected by release of the red maple stump sprouts, but release had no significant effect on the diameter growth of the red oak advance reproduction.

Length of clear stem was retarded during the 5-year period by release, but during this period red oak cleared up at a faster rate than red maple.

Changes in 5-year crown class indicate that

release had a minor effect on red oak, where crowns retrogressed heavily in dominance in both released and control trees. However, released red maple codominants were definitely more dominant than controls 5 years after release.

Mortality was slight in all of the stem categories.

Grapevines were not a problem in this study.

As a first observation, it appears that red oak stems were released too soon or were not released heavily enough. We found that the competition affecting these red oak stems was not largely from sprout regrowth of the stems cut during release—as it was in the study of yellow-poplar and black cherry on the better sites—but came mostly from sprout growth of American chestnut and from chestnut oak stump sprouts outside the 5-foot radius. Had the second growth stems of chestnut oak been older at the time of clearcutting, stump sprouting would have been less vigorous. This leads us to believe that it might have been practicable to release these red oak stems at this early age if the release had been carried out to a greater radius around the stem than 5 feet—or if the clearcutting had been delayed until the stand was older, or both.

On the other hand, the release of red maple stump sprouts appears to have been beneficial, probably because they were so much taller originally.

An additional interesting observation is that very little of the competition to the released red maple stump sprouts came from regrowth of the many stems cut in each clump at release time. Few of these have resprouted.

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6 p. (USDA Forest Serv. Res. Pap. NE-303)

Study results from a crop-tree release of red maple stump sprouts and northern red oak advance reproduction in a 7-year-old hardwood stand on a fair site indicated that the release: (1) had no effect on the height growth of either species, (2) did positively favor diameter growth of the red maple, but did not affect diameter growth of the red oak, and (3) had little effect on crown position of red oak but favored retention of dominance among codominant red maple sprouts.

241:242:243:228.5:176.1

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MANUSCRIPT RECEIVED FOR PUBLICATION 27 FEBRUARY 1974

Log and Tree Sawing Times for Hardwood Mills

ABSTRACT

Data on 6,850 logs and 1,181 trees were analyzed to predict sawing times. For both logs and trees, regression equations were derived that express (in minutes) sawing time per log or tree and per Mbf. For trees, merchantable height is expressed in number of logs as well as in feet. One of the major uses for the tables of average sawing times is as a bench mark against which individual mills can make comparisons.

This publication is based on a paper originally presented at the 27th Annual Meeting of the Forest Products Research Society, June 26, 1973, in Anaheim, California.

Introduction

Most sawmill operations are centered around the headsaw. The headsaw is the hub, for all other sawmill operations are geared to the speed with which logs are sawn. Yet many mill owners and foremen do not know how much time it takes to saw logs of different dimensions. Information on average log-sawing time allows mill owners to evaluate their production, to use available computer programs to determine the dollar worth of sawlogs, to evaluate the time saved by a resaw, and to determine the effect of a change in average log size. This information will also be useful in timber appraisal.

Profit is a major incentive for mill owners and it is directly related to cost (profit = revenue − cost); anything that reduces cost increases profits. Sawing is one of the cost items; therefore, reducing the average sawing time per log or per thousand board feet will increase profits.

Sample Data

The data on log-sawing times were collected during 47 studies conducted at 20 different mills, of which 7 used circular saws and 13 used bandsaws. Eight of the mills had resaws. The data cover 18 different species and 6,850 logs. The data on tree-sawing times came from 24 studies at 11 mills, of which 3 used circular saws and 8 bandsaws. Four of the bandsaw mills had resaws. The sample data covered 8 different species, 1,181 trees and 3,570 logs.

Procedure

Sawing time, as used in this study, commences when the log is rolled out onto the carriage and continues until the log is completely sawn, the dog board or cant is released, and the carriage returns and stops in front of the log deck ready for the next log. Any delay of 20 seconds or more during the sawing of a log is recorded and deducted from the sawing time. Sawing time is broken down into two categories and each is analyzed from two different standpoints. The two categories are log-sawing time and tree-sawing time, and each is expressed as sawing time (in minutes) per log or tree and per Mbf.

Before analysis, the sawing time data were split into three groups. The first group was used to develop the model, the second group to obtain the coefficients for the model, and the third group to test the final model.

Variables

The factors affecting sawing time can be grouped into three main categories:

1. Characteristics of the log or tree.
2. Type of sawmill equipment.
3. Method of sawing and thickness pattern used.

Log or tree characteristics include species, diameter or dbh., length or merchantable height (either in feet or in number of logs), grade, volume, form class, and scalable defects. Some of these variables are expressed as combinations of other variables; for example, volume is a function of diameter, length, and form.

Under type of sawmill equipment, the primary variable was type of headsaw, band or circular. Other variables considered were the presence or absence of a debarker, a resaw, and a chipper.

Under the last category, method of sawing and thickness pattern, only the latter was tested because all sawyers sawed for grade, turning the log when the grade dropped and also setting out taper.

Table 1.—Independent variables

Logs		Trees	
D	Diameter	DBH	Diameter breast height
L	Length	FT	Merchantable height in feet
D SQ	Diameter squared	NL	" " " no. of logs
L SQ	Length squared	DBH SQ	Diameter breast height squared
D SQ × L		FT SQ	Merchantable height in feet squared
1/D		NL SQ	" " " no. of logs squared
1/L		DBH SQ × FT	
1/D SQ		DBH SQ × NL	
1/L SQ		1/DBH	
1/D SQ × L		1/FT	
SP	Species as dummy variable	1/NL	
GR	Grade " " "	1/DBH SQ	
UD	Unsound defects " " "	1/FT SQ	
SD	Soundness " " "	1/NL SQ	
AD	All scalable defects " " "	1/DBH SQ × FT	
B-C	Band or circular saw " " "	1/DBH SQ × NL	
TP	Thickness pattern " " "	FM	Form class as dummy variable
R	Presence or absence of resaw " " "	SP	Species " " "
DB	" " " " debarker " " "	GR	Grade " " "
CH	" " " " chipper " " "	UD	Unsound defects " " "
		SD	Soundness " " "
		AD	All scalable defects " " "
		B-C	Band or circular saw as dummy variable
		TP	Thickness pattern " " "
		R	Presence or absence of resaw " " "
		DB	Presence or absence of debarker " " "
		CH	Presence or absence of chipper " " "
(The interaction terms between the dummy variables and all other variables were also formed)		(The interaction terms between the dummy variables and all other variables were also formed)	

Table 2.—Regression coefficients and associated T-values
(Log sawing time)

Independent variable	Regression coefficient	T-value
Log sawing time (min.)		
Intercept	0.85969654	16.56**
D	0.00213389	5.55**
D SQ × L	0.00067173	21.98**
L SQ	0.00077287	2.46*
R × L	−0.02651734	2.97**
R × L SQ	−0.00030880	0.49[a]
R × D SQ × L	−0.00026255	22.27**
Log sawing time per Mbf. (min.)		
Intercept	14.87645	17.14**
1/D SQ	619.15918	2.93**
1/D SQ × L	23624.93360	10.11**
1/L SQ	844.20239	8.79**
R	−8.18146	13.82**
R × 1/D SQ × L	−8607.90625	8.60**
SD > 25%	15.51666	19.48**

** Significant at the 1 percent probability level.
* Significant at the 5 percent probability level.
[a] Although not significant, this term is retained in the equation because its presence prevents the values at the sawing times of the 8 to 10-inch diameter logs in the 13 to 16 foot range from decreasing in value.

Developing the Model

The data selected for developing the model were analyzed using the least-squares principle for fitting a multiple linear regression model. The initial selection of independent variables was made by compiling two simple correlation matrices, one for the log data and one for the tree data. These matrices were made up of the log, tree and mill characteristics (table 1). Some of the variables are transformations and combinations of other variables and others are dummy variables. Also all the interaction terms between the dummy variable and all other variables were used. With the correlation matrix as a guide, the variables to be used in the model searching were selected. A stepwise regression fitting procedure was used to select those independent variables that had a significant effect on the dependent variable, sawing time. In the tree sawing time models, equations were developed using merchantable height both in feet and in number of logs.

The variables found to be significant, their regression coefficients, and the associated T-values are given in tables 2 and 3.

Some of the more important factors that add variation that cannot be accounted for adequately are:

1. Differences among the 20 mills.

Table 3.—Regression coefficients and associated T-values

(Tree sawing time)

Independent variable	Merchantable height in no. of logs		Merchantable height in feet	
	Regression coefficient	T-values	Regression coefficient	T-values
Tree sawing time (min.)				
Intercept	3.92863000	11.52**	4.17154000	12.09**
DBH SQ	0.00722676	6.44**	0.00639411	5.64**
DBH SQ × NL (FT)	0.00463075	21.17**	0.00030065	21.66**
1/DBH SQ × NL (FT)	−277.30493000	4.38**	−5034.36719000	4.96**
R × DBH SQ	−0.00512604	6.97**	−0.00465374	6.31**
R × NL (FT)	−1.10542000	9.01**	−0.07443058	9.58**
Tree sawing time per Mbf. (min.)				
Intercept	33.79843	23.55**	34.11577000	23.73**
1/DBH SQ	3750.99023	16.47**	3722.54956000	16.35**
NL	−2.83026	7.79**	−0.18433136	8.04**
R	−10.35313	9.30**	−10.35213000	9.32**
R × 1/DBH SQ	−2351.58008	7.60**	−2355.91797000	7.63**
SD > 25%	10.66874	4.00**	10.65716000	4.00**

** Significant at the 1 percent probability level.

2. Differences among the one to three different sawyers per mill.
3. Different capacities of mills.
4. Vastly different power plants, some up to standard and others way below.
5. Differences in maintenance: some mills have good preventive maintenance and others wait until a breakdown occurs before making repairs.
6. Frequency of changing or sharpening saws.

Thickness pattern was found to be significant but was not used in the analysis. Using dummy variables and plots of the residuals showed a clear break when a mill was cutting 25 percent or more of 6/4 and thicker sawn lumber or timbers. Using this breakdown seemed logical, but the logs that fell in this category were all sawn at bandsaw mills with a resaw and, therefore, this dummy variable was highly correlated with the dummy variable for resaw. In the regression analysis, once the variable for resaw entered the equation, then the variable for 6/4 > 25 percent became nonsignificant. There were two problems with running these data separately: First, there were not enough data for a separate run, and second, they applied only to a bandsaw mill with a resaw. Therefore, this variable was dropped.

Sawing Time Results, Tests, and Discussion

The equations predict sawing time per log or tree better than sawing time per Mbf. In the log sawing time equations, the adjusted R^2s are .72 and .54, respectively, and for tree-sawing time, they are .82 and .69 (table 4). The variance ratio test was used to test for differences in the two sets of observations. The test is:

$$F = \frac{n_1 + n_2 - 2p}{p} \quad \frac{\mathcal{S}_c - (\mathcal{S}_1 + \mathcal{S}_2)}{\mathcal{S}_c}$$

where: n_1 = number of observations in first sample
n_2 = number of observations in test sample
p = number of parameters
$\mathcal{S}_c$ = sum of squared residuals for pooled first and second sample
$\mathcal{S}_1$ = sum of squared residuals for first sample
$\mathcal{S}_2$ = sum of squared residuals for test sample

The statistic F has an F distribution with $n_1 + n_2$ and p degrees of freedom if the observations are normally distributed.

If the F-value is nonsignificant, then the hypothesis that the parameters of the first and

Table 4.—Relevant statistics for the four sawing-time prediction models

Statistic		Log sawing time		Tree sawing time	
		Per log	Per Mbf.	Per tree	Per Mbf.
R^2		0.72	0.54	0.82	0.69
Standard error of estimate		.78	12.54	2.10	7.92
S.T.	Mean	2.76	32.30	8.90	28.36
	SD	1.48	18.63	4.90	14.34
Diam. or dbh	Mean	14.26	14.27	20.04	20.22
	SD	4.28	4.28	5.37	5.38
Length	Mean	12.54	12.55	40.32	40.70
	SD	2.64	2.64	12.29	12.30
No. of logs	Mean	—	—	2.55	2.57
	SD	—	—	.77	.77
No. of observations		6629	6608	1001	961

test data are the same is accepted, and the equation for the combined data is used.

The F-values for all equations are:

Tree-sawing time	1.36
Tree-sawing time per Mbf.	2.55
Log-sawing time	8.65**
Log-sawing time per Mbf.	0.013

** Significant at the 1 percent probability level.

The F-statistic for three of the tests is nonsignificant, but for log sawing time, the F-statistic is significant because the $\mathscr{S}_c$ is small (0.6105), so that the difference between coefficients of the first and test sample are large relative to $\mathscr{S}_c$. Therefore, tables of predicted values were developed using the coefficients of the three groups. The developing data table varied an average of 1 percent from the combined data table and the test data table varied an average of 7 percent. Therefore, even though the F-statistic was significant, the table is accepted because of the small differences among the three tables.

Tables 5 to 16 (Appendix) were produced using the models developed. The tables show in minutes the average time required to saw logs or trees grouped according to the following criteria: diameter inside bark, small end (dib), diameter breast height (dbh), length in feet, height by number of logs, presence or absence of a resaw, and scaling deduction greater than 25 percent in the tables showing sawing time per Mbf.

Tables 14 and 16, for tree-sawing time per Mbf with scaling deductions greater than 25 percent and with and without resaw, need more data before they can be used with confidence, even though the T-value of the scaling deduction coefficient is highly significant.

Use of the Study Results

There are many uses for the results of this study. First, the data on tree-sawing times can be used in making timber appraisals. One of the factors presently used is the average manufacturers cost in the appraisal zone. With the data for tree-sawing times, manufacturing costs can be adjusted for timber sales that are either above or below average size. Second, since the data is from many mills, an individual mill owner can compare sawing times at his mill to the average. Such an evaluation may suggest changes in sawing procedure. Third, a sawmill operator using one of several available computer programs[1] that require sawing times to provide mill analysis information, or to provide the dollar worth of sawlogs, could use the actual data developed here or could use the variables found to be significant and develop individual mill coefficients. Fourth, the mill owner could determine what type of change in production he could expect by adding or removing a resaw at his mill. Fifth, if the mill owner knows that the average diameter and length of the logs he receives at his mill will be changing, he can predict what effect this will have on his production and costs.

[1] For example see Adams, Edward L. "SOLVE: A Computer Program for Determining the Maximum Value of Hardwood Sawlogs" USDA Forest Service Research Paper NE-229, 1972.

Table 5.—Log sawing time in minutes

(Mill has resaw)

dib	Log length								
	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet
8	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.10	1.11
9	1.12	1.13	1.15	1.16	1.18	1.20	1.22	1.24	1.26
10	1.22	1.24	1.26	1.29	1.31	1.34	1.37	1.39	1.42
11	1.33	1.36	1.39	1.43	1.46	1.50	1.53	1.57	1.60
12	1.46	1.50	1.54	1.58	1.62	1.67	1.71	1.76	1.80
13	1.59	1.64	1.69	1.75	1.80	1.85	1.91	1.96	2.02
14	1.74	1.80	1.86	1.92	1.99	2.05	2.12	2.19	2.26
15	1.89	1.97	2.04	2.12	2.19	2.27	2.35	2.43	2.51
16	2.06	2.15	2.23	2.32	2.41	2.50	2.59	2.68	2.78
17	2.24	2.34	2.44	2.54	2.64	2.75	2.85	2.96	3.06
18	2.43	2.54	2.66	2.77	2.89	3.01	3.13	3.25	3.37
19	2.63	2.76	2.89	3.02	3.15	3.28	3.42	3.55	3.69
20	2.84	2.99	3.13	3.28	3.43	3.57	3.72	3.87	4.03
21	3.06	3.22	3.39	3.55	3.71	3.88	4.05	4.21	4.38
22	3.29	3.47	3.65	3.84	4.02	4.20	4.38	4.57	4.76
23	3.54	3.74	3.93	4.13	4.33	4.54	4.74	4.94	5.15
24	3.79	4.01	4.23	4.45	4.67	4.89	5.11	5.33	5.55
25	4.06	4.29	4.53	4.77	5.01	5.25	5.49	5.74	5.98
26	4.33	4.59	4.85	5.11	5.37	5.63	5.89	6.16	6.42
27	4.62	4.90	5.18	5.46	5.74	6.03	6.31	6.60	6.88
28	4.92	5.22	5.52	5.83	6.13	6.44	6.74	7.05	7.36
29	5.22	5.55	5.88	6.20	6.53	6.86	7.19	7.52	7.85
30	5.54	5.89	6.24	6.60	6.95	7.30	7.66	8.01	8.37
31	5.87	6.25	6.62	7.00	7.38	7.76	8.14	8.52	8.90
32	6.21	6.61	7.02	7.42	7.82	8.23	8.63	9.04	9.44
33	6.57	6.99	7.42	7.85	8.28	8.71	9.14	9.57	10.01
34	6.93	7.38	7.84	8.29	8.75	9.21	9.67	10.13	10.59
35	7.30	7.78	8.27	8.75	9.24	9.72	10.21	10.70	11.19
36	7.69	8.20	8.71	9.22	9.74	10.25	10.77	11.29	11.80
37	8.08	8.62	9.16	9.71	10.25	10.80	11.34	11.89	12.44
38	8.49	9.06	9.63	10.20	10.78	11.36	11.93	12.51	13.09
39	8.90	9.51	10.11	10.72	11.32	11.93	12.54	13.15	13.76
40	9.33	9.97	10.60	11.24	11.88	12.52	13.16	13.80	14.44

Shaded area indicates limits of basic data.

Table 6.—Log sawing time in minutes

(no resaw)

dib	Log length								
	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet
8	1.39	1.45	1.50	1.56	1.62	1.69	1.75	1.82	1.88
9	1.52	1.58	1.65	1.72	1.80	1.87	1.95	2.02	2.10
10	1.66	1.74	1.82	1.91	1.99	2.08	2.16	2.25	2.35
11	1.82	1.91	2.01	2.11	2.20	2.31	2.41	2.51	2.62
12	1.99	2.10	2.21	2.32	2.44	2.56	2.67	2.79	2.91
13	2.18	2.30	2.43	2.56	2.69	2.83	2.96	3.10	3.23
14	2.38	2.53	2.67	2.82	2.97	3.12	3.27	3.43	3.58
15	2.60	2.76	2.93	3.10	3.26	3.44	3.61	3.78	3.96
16	2.83	3.02	3.20	3.39	3.58	3.77	3.96	4.16	4.36
17	3.08	3.29	3.49	3.71	3.92	4.13	4.35	4.56	4.78
18	3.34	3.57	3.80	4.04	4.27	4.51	4.75	4.99	5.23
19	3.62	3.88	4.13	4.39	4.65	4.91	5.18	5.44	5.71
20	3.91	4.19	4.48	4.76	5.05	5.34	5.63	5.92	6.21
21	4.22	4.53	4.84	5.15	5.47	5.78	6.10	6.42	6.74
22	4.54	4.88	5.22	5.56	5.91	6.25	6.60	6.94	7.29
23	4.88	5.25	5.62	5.99	6.36	6.74	7.11	7.49	7.87
24	5.23	5.63	6.04	6.44	6.84	7.25	7.66	8.07	8.48
25	5.60	6.03	6.47	6.91	7.34	7.78	8.22	8.66	9.11
26	5.98	6.45	6.92	7.39	7.86	8.34	8.81	9.29	9.77
27	6.38	6.89	7.39	7.90	8.40	8.91	9.42	9.93	10.45
28	6.80	7.33	7.88	8.42	8.96	9.51	10.06	10.61	11.16
29	7.22	7.80	8.38	8.96	9.54	10.13	10.71	11.30	11.89
30	7.67	8.28	8.90	9.52	10.15	10.77	11.40	12.02	12.65
31	8.12	8.78	9.44	10.10	10.77	11.43	12.10	12.77	13.44
32	8.60	9.30	10.00	10.70	11.41	12.12	12.83	13.54	14.25
33	9.09	9.83	10.58	11.32	12.07	12.82	13.58	14.33	15.09
34	9.59	10.38	11.17	11.96	12.76	13.55	14.35	15.15	15.95
35	10.11	10.94	11.78	12.62	13.46	14.30	15.15	15.99	16.84
36	10.64	11.52	12.41	13.29	14.18	15.07	15.96	16.86	17.75
37	11.19	12.12	13.05	13.99	14.93	15.87	16.81	17.75	18.69
38	11.75	12.73	13.72	14.70	15.69	16.68	17.67	18.66	19.66
39	12.33	13.36	14.40	15.44	16.48	17.52	18.56	19.60	20.65
40	12.92	14.01	15.10	16.19	17.28	18.38	19.47	20.57	21.67

Shaded area indicates limits of basic data.

Table 7.—Log sawing time in Minutes per Mbf.

(Mill has resaw; scaling defect < 25%)

dib	Log length								
	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet
8	58.89	52.86	48.28	44.68	41.79	39.41	37.44	35.76	34.33
9	50.70	45.36	41.32	38.17	35.65	33.60	31.89	30.45	29.22
10	44.85	39.99	36.35	33.52	31.26	29.43	27.92	26.65	25.57
11	40.52	36.02	32.66	30.07	28.02	26.35	24.98	23.84	22.87
12	37.22	33.00	29.87	27.45	25.55	24.01	22.75	21.70	20.81
13	34.66	30.65	27.69	25.41	23.63	22.19	21.01	20.03	19.21
14	32.62	28.79	25.96	23.80	22.10	20.74	19.63	18.71	17.94
15	30.98	27.28	24.56	22.49	20.87	19.58	18.52	17.65	16.92
16	29.64	26.05	23.42	21.42	19.86	18.62	17.61	16.78	16.08
17	28.52	25.03	22.48	20.54	19.03	17.83	16.86	16.05	15.38
18	27.59	24.18	21.68	19.80	18.33	17.17	16.22	15.45	14.80
19	26.80	23.45	21.01	19.17	17.74	16.61	15.69	14.94	14.31
20	26.13	22.84	20.44	18.63	17.23	16.13	15.23	14.50	13.89
21	25.55	22.30	19.95	18.17	16.80	15.71	14.84	14.12	13.52
22	25.04	21.84	19.52	17.77	16.42	15.36	14.50	13.79	13.21
23	24.60	21.44	19.15	17.42	16.09	15.04	14.20	13.51	12.94
24	24.22	21.09	18.82	17.12	15.81	14.77	13.94	13.26	12.70
25	23.88	20.78	18.53	16.85	15.55	14.53	13.71	13.04	12.49
26	23.58	20.50	18.27	16.61	15.32	14.31	13.50	12.84	12.30
27	23.31	20.26	18.05	16.39	15.12	14.12	13.32	12.67	12.13
28	23.07	20.04	17.84	16.20	14.94	13.95	13.16	12.51	11.98
29	22.85	19.84	17.66	16.03	14.78	13.80	13.01	12.37	11.84
30	22.66	19.66	17.49	15.88	14.64	13.66	12.88	12.25	11.72
31	22.48	19.50	17.34	15.74	14.50	13.54	12.76	12.13	11.61
32	22.32	19.35	17.21	15.61	14.38	13.42	12.65	12.03	11.51
33	22.18	19.22	17.08	15.49	14.28	13.32	12.56	11.93	11.42
34	22.05	19.10	16.97	15.39	14.18	13.23	12.47	11.85	11.34
35	21.92	18.98	16.87	15.29	14.08	13.14	12.38	11.77	11.26
36	21.81	18.88	16.77	15.20	14.00	13.06	12.31	11.70	11.19
37	21.71	18.79	16.69	15.12	13.92	12.99	12.24	11.63	11.13
38	21.61	18.70	16.61	15.05	13.85	12.92	12.17	11.57	11.07
39	21.53	18.62	16.53	14.98	13.79	12.86	12.11	11.51	11.02
40	21.45	18.55	16.46	14.91	13.73	12.80	12.06	11.46	10.97

Shaded area indicates limits of basic data.

Table 8.—Log sawing time in minutes per Mbf.

(mill has resaw; scaling defect > 25%)

dib	Log length								
	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet
8	74.77	68.74	64.15	60.55	57.66	55.29	53.31	51.64	50.21
9	66.58	61.24	57.20	54.05	51.53	49.47	47.77	46.33	45.10
10	60.72	55.87	52.22	49.39	47.14	45.31	43.80	42.53	41.45
11	56.39	51.90	48.54	45.95	43.89	42.23	40.86	39.71	38.74
12	53.10	48.88	45.74	43.33	41.42	39.89	38.63	37.58	36.69
13	50.53	46.53	43.56	41.29	39.50	38.07	36.89	35.91	35.09
14	48.50	44.67	41.83	39.67	37.98	36.62	35.51	34.59	33.82
15	46.86	43.16	40.44	38.37	36.75	35.45	34.40	33.52	32.79
16	45.51	41.93	39.30	37.30	35.74	34.50	33.49	32.65	31.95
17	44.40	40.91	38.35	36.41	34.91	33.71	32.73	31.93	31.26
18	43.47	40.05	37.56	35.67	34.21	33.04	32.10	31.32	30.68
19	42.68	39.33	36.89	35.05	33.62	32.48	31.57	30.81	30.18
20	42.00	38.71	36.32	34.51	33.11	32.00	31.11	30.37	29.76
21	41.42	38.18	35.82	34.05	32.68	31.59	30.71	30.00	29.40
22	40.92	37.72	35.40	33.65	32.30	31.23	30.37	29.67	29.09
23	40.48	37.32	35.02	33.30	31.97	30.92	30.08	29.39	28.81
24	40.10	36.97	34.70	32.99	31.68	30.65	29.82	29.14	28.57
25	39.76	36.65	34.41	32.72	31.43	30.41	29.59	28.92	28.36
26	39.45	36.38	34.15	32.48	31.20	30.19	29.38	28.72	28.17
27	39.19	36.13	33.92	32.27	31.00	30.00	29.20	28.55	28.01
28	38.95	35.91	33.72	32.08	30.82	29.83	29.04	28.39	27.86
29	38.73	35.71	33.54	31.91	30.66	29.68	28.89	28.25	27.72
30	38.54	35.54	33.37	31.75	30.51	29.54	28.76	28.12	27.60
31	38.36	35.37	33.22	31.61	30.38	29.41	28.64	28.01	27.49
32	38.20	35.23	33.08	31.49	30.26	29.30	28.53	27.91	27.39
33	38.05	35.09	32.96	31.37	30.15	29.20	28.43	27.81	27.30
34	37.92	34.97	32.85	31.26	30.05	29.10	28.34	27.73	27.22
35	37.80	34.86	32.74	31.17	29.96	29.02	28.26	27.65	27.14
36	37.69	34.76	32.65	31.08	29.88	28.94	28.18	27.57	27.07
37	37.59	34.66	32.56	31.00	29.80	28.86	28.11	27.51	27.01
38	37.49	34.58	32.48	30.92	29.73	28.80	28.05	27.45	26.95
39	37.40	34.50	32.41	30.85	29.66	28.73	27.99	27.39	26.89
40	37.32	34.42	32.34	30.79	29.60	28.68	27.94	27.34	26.84

Shaded area indicates limits of basic data.

Table 9.—Log sawing time in minutes per Mbf.

(no resaw; scaling defect < 25%)

dib	Log length								
	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet
8	83.88	75.99	69.91	65.09	61.17	57.94	55.23	52.91	50.92
9	72.17	65.35	60.13	56.01	52.69	49.95	47.66	45.72	44.05
10	63.79	57.74	53.13	49.52	46.62	44.24	42.25	40.57	39.13
11	57.59	52.11	47.96	44.72	42.13	40.01	38.25	36.76	35.49
12	52.87	47.83	44.02	41.07	38.71	36.79	35.20	33.87	32.73
13	49.20	44.49	40.96	38.23	36.05	34.29	32.83	31.61	30.57
14	46.29	41.85	38.53	35.97	33.94	32.30	30.95	29.82	28.87
15	43.94	39.72	36.57	34.15	32.24	30.70	29.44	28.38	27.49
16	42.02	37.97	34.97	32.66	30.85	29.39	28.19	27.20	26.36
17	40.43	36.52	33.64	31.43	29.69	28.30	27.17	26.22	25.43
18	39.09	35.31	32.52	30.39	28.73	27.39	26.30	25.40	24.64
19	37.96	34.29	31.58	29.52	27.91	26.62	25.57	24.71	23.98
20	37.00	33.41	30.77	28.77	27.21	25.96	24.95	24.11	23.41
21	36.17	32.66	30.08	28.13	26.61	25.40	24.41	23.60	22.93
22	35.45	32.00	29.48	27.57	26.09	24.91	23.95	23.16	22.50
23	34.82	31.43	28.95	27.08	25.63	24.48	23.54	22.78	22.14
24	34.27	30.93	28.49	26.66	25.23	24.10	23.19	22.44	21.81
25	33.78	30.49	28.09	26.28	24.88	23.77	22.87	22.14	21.53
26	33.35	30.10	27.73	25.95	24.57	23.48	22.60	21.87	21.27
27	32.97	29.75	27.41	25.65	24.29	23.21	22.35	21.64	21.05
28	32.62	29.44	27.12	25.38	24.04	22.98	22.13	21.43	20.85
29	32.31	29.16	26.86	25.14	23.82	22.77	21.93	21.24	20.67
30	32.04	28.90	26.63	24.93	23.61	22.58	21.75	21.07	20.50
31	31.78	28.67	26.42	24.73	23.43	22.41	21.58	20.91	20.35
32	31.56	28.47	26.23	24.56	23.27	22.25	21.44	20.77	20.22
33	31.35	28.28	26.06	24.39	23.12	22.11	21.30	20.64	20.10
34	31.16	28.11	25.90	24.25	22.98	21.98	21.18	20.53	19.99
35	30.98	27.95	25.75	24.11	22.85	21.86	21.07	20.42	19.88
36	30.82	27.80	25.62	23.99	22.74	21.75	20.96	20.32	19.79
37	30.68	27.67	25.50	23.87	22.63	21.65	20.87	20.23	19.70
38	30.54	27.55	25.38	23.77	22.53	21.56	20.78	20.15	19.63
39	30.42	27.43	25.28	23.67	22.44	21.47	20.70	20.07	19.55
40	30.30	27.33	25.18	23.58	22.36	21.39	20.63	20.00	19.48

Shaded area indicates limits of basic data.

Table 10.—Log sawing time in minutes per Mbf.

(no resaw; scaling defect > 25%)

dib	Log length								
	8 feet	9 feet	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet
8	99.76	91.87	85.78	80.96	77.05	73.82	71.10	68.79	66.80
9	88.05	81.23	76.01	71.89	68.56	65.83	63.54	61.59	59.92
10	79.67	73.62	69.01	65.40	62.49	60.11	58.13	56.45	55.01
11	73.47	67.99	63.84	60.60	58.00	55.88	54.12	52.64	51.37
12	68.75	63.70	59.90	56.94	54.59	52.67	51.08	49.74	48.60
13	65.08	60.37	56.84	54.10	51.93	50.17	48.71	47.49	46.45
14	62.17	57.73	54.41	51.85	49.82	48.18	46.83	45.70	44.74
15	59.82	55.59	52.45	50.03	48.12	46.58	45.31	44.26	43.36
16	57.90	53.85	50.84	48.54	46.72	45.27	44.07	43.08	42.24
17	56.30	52.40	49.51	47.30	45.57	44.18	43.04	42.10	41.30
18	54.97	51.19	48.40	46.27	44.60	43.27	42.18	41.28	40.52
19	53.84	50.16	47.45	45.39	43.78	42.50	41.45	40.58	39.86
20	52.87	49.29	46.65	44.65	43.09	41.84	40.83	39.99	39.29
21	52.04	48.53	45.96	44.00	42.48	41.27	40.29	39.48	38.80
22	51.32	47.88	45.36	43.45	41.96	40.78	39.83	39.04	38.38
23	50.70	47.31	44.83	42.96	41.51	40.35	39.42	38.65	38.01
24	50.15	46.81	44.37	42.53	41.11	39.98	39.06	38.31	37.69
25	49.66	46.37	43.97	42.16	40.76	39.65	38.75	38.02	37.40
26	49.23	45.97	43.61	41.82	40.44	39.35	38.47	37.75	37.15
27	48.84	45.63	43.28	41.53	40.17	39.09	38.22	37.51	36.93
28	48.50	45.31	43.00	41.26	39.92	38.86	38.00	37.30	36.72
29	48.19	45.03	42.74	41.02	39.69	38.65	37.80	37.11	36.54
30	47.91	44.78	42.51	40.80	39.49	38.46	37.62	36.94	36.38
31	47.66	44.55	42.30	40.61	39.31	38.28	37.46	36.79	36.23
32	47.43	44.34	42.11	40.43	39.14	38.13	37.31	36.65	36.10
33	47.22	44.15	41.93	40.27	38.99	37.99	37.18	36.52	35.98
34	47.03	43.98	41.77	40.12	38.85	37.86	37.06	36.40	35.86
35	46.86	43.82	41.63	39.99	38.73	37.74	36.94	36.30	35.76
36	46.70	43.68	41.50	39.86	38.61	37.63	36.84	36.20	35.67
37	46.55	43.54	41.37	39.75	38.51	37.53	36.74	36.11	35.58
38	46.42	43.42	41.26	39.65	38.41	37.44	36.66	36.02	35.50
39	46.29	43.31	41.16	39.55	38.32	37.35	36.58	35.95	35.43
40	46.18	43.20	41.06	39.46	38.23	37.27	36.50	35.88	35.36

Shaded area indicates limits of basic data.

Table 11.—Tree sawing time in minutes

(mill has resaw)

dbh	Merchantable height								
	1.0 log	1.5 log	2.0 log	2.5 log	3.0 log	3.5 log	4.0 log	4.5 log	5.0 log
10	0.72	1.33	1.47						
11	1.35	1.84	1.95						
12	1.87	2.29	2.39						
13	2.32	2.71	2.82						
14	2.73	3.10	3.24	3.28					
15	3.11	3.48	3.66	3.75	3.80	3.83			
16	3.46	3.86	4.08	4.23	4.35	4.44	4.52	4.59	4.65
17	3.81	4.25	4.52	4.73	4.91	5.08	5.23	5.37	5.51
18	4.15	4.63	4.97	5.25	5.51	5.75	5.98	6.20	6.41
19	4.49	5.02	5.44	5.80	6.13	6.45	6.76	7.06	7.36
20	4.82	5.43	5.92	6.36	6.78	7.18	7.58	7.98	8.36
21	5.16	5.84	6.41	6.95	7.46	7.95	8.44	8.93	9.41
22	5.51	6.27	6.93	7.56	8.16	8.76	9.35	9.93	10.51
23	5.86	6.71	7.47	8.19	8.90	9.60	10.29	10.97	11.66
24	6.22	7.16	8.02	8.85	9.66	10.47	11.27	12.06	12.85
25	6.59	7.63	8.60	9.54	10.46	11.38	12.29	13.19	14.10
26	6.96	8.11	9.19	10.25	11.29	12.32	13.35	14.37	15.39
27	7.35	8.61	9.81	10.98	12.14	13.30	14.45	15.59	16.74
28	7.75	9.13	10.45	11.75	13.03	14.31	15.59	16.86	18.13
29	8.15	9.66	11.11	12.54	13.95	15.36	16.77	18.17	19.57
30	8.57	10.21	11.79	13.35	14.90	16.45	17.99	19.53	21.07
31	9.00	10.77	12.49	14.19	15.89	17.57	19.25	20.93	22.61
32	9.45	11.35	13.22	15.06	16.90	18.73	20.56	22.38	24.21
33	9.90	11.95	13.96	15.96	17.94	19.92	21.90	23.88	25.85
34	10.36	12.57	14.73	16.88	19.02	21.16	23.29	25.42	27.55
35	10.84	13.20	15.52	17.83	20.13	22.42	24.71	27.00	29.29
36	11.33	13.85	16.34	18.81	21.27	23.73	26.18	28.64	31.09
37	11.84	14.52	17.17	19.81	22.44	25.07	27.69	30.31	32.93
38	12.35	15.21	18.03	20.84	23.64	26.44	29.24	32.04	34.83
39	12.88	15.91	18.91	21.90	24.88	27.85	30.83	33.80	36.78
40	13.42	16.63	19.81	22.98	26.14	29.30	32.46	35.62	38.77

Shaded area indicates limits of basic data.

Table 12.—Tree sawing time in minutes

(no resaw)

dbh	Merchantable height								
	1.0 log	1.5 log	2.0 log	2.5 log	3.0 log	3.5 log	4.0 log	4.5 log	5.0 log
10	2.34	3.50	4.19	4.70	5.12	5.48	5.81	6.12	6.41
11	3.07	4.12	4.78	5.29	5.72	6.11	6.47	6.82	7.15
12	3.71	4.69	5.34	5.87	6.33	6.75	7.16	7.54	7.92
13	4.29	5.23	5.89	6.45	6.95	7.42	7.87	8.31	8.73
14	4.84	5.76	6.45	7.05	7.60	8.12	8.62	9.11	9.60
15	5.36	6.30	7.02	7.67	8.27	8.85	9.41	9.97	10.52
16	5.88	6.83	7.61	8.31	8.97	9.62	10.25	10.87	11.49
17	6.40	7.38	8.21	8.98	9.71	10.43	11.13	11.83	12.52
18	6.91	7.95	8.84	9.68	10.49	11.28	12.06	12.83	13.60
19	7.44	8.53	9.50	10.41	11.30	12.17	13.03	13.89	14.74
20	7.98	9.14	10.18	11.17	12.15	13.10	14.06	15.00	15.94
21	8.53	9.76	10.89	11.97	13.03	14.08	15.13	16.17	17.20
22	9.09	10.41	11.62	12.80	13.96	15.11	16.25	17.38	18.52
23	9.68	11.08	12.39	13.67	14.93	16.18	17.42	18.66	19.90
24	10.28	11.77	13.19	14.57	15.93	17.29	18.64	19.99	21.33
25	10.90	12.49	14.01	15.50	16.98	18.45	19.91	21.37	22.83
26	11.53	13.24	14.87	16.48	18.07	19.65	21.23	22.81	24.38
27	12.19	14.01	15.76	17.48	19.20	20.90	22.61	24.30	26.00
28	12.87	14.80	16.68	18.53	20.37	22.20	24.03	25.85	27.68
29	13.57	15.63	17.63	19.61	21.58	23.54	25.50	27.46	29.41
30	14.29	16.48	18.61	20.73	22.83	24.93	27.03	29.12	31.21
31	15.04	17.36	19.63	21.88	24.13	26.37	28.60	30.84	33.07
32	15.80	18.26	20.68	23.08	25.46	27.85	30.23	32.61	34.98
33	16.59	19.19	21.76	24.30	26.84	29.38	31.91	34.43	36.96
34	17.40	20.15	22.87	25.57	28.26	30.95	33.64	36.32	39.00
35	18.23	21.14	24.01	26.87	29.72	32.57	35.42	38.26	41.10
36	19.08	22.15	25.19	28.21	31.23	34.24	37.25	40.25	43.26
37	19.96	23.20	26.40	29.59	32.77	35.95	39.13	42.30	45.48
38	20.86	24.27	27.64	31.00	34.36	37.71	41.06	44.41	47.76
39	21.78	25.36	28.92	32.46	35.99	39.52	43.05	46.58	50.10
40	22.73	26.49	30.22	33.95	37.66	41.37	45.08	48.79	52.50

Shaded area indicates limits of basic data.

Table 13.—Tree sawing time in minutes per Mbf.

(mill has resaw; scaling defect < 25%)

dbh	Merchantable height								
	1.0 log	1.5 log	2.0 log	2.5 log	3.0 log	3.5 log	4.0 log	4.5 log	5.0 log
10	34.61	33.19	31.78	30.36	28.95	27.53	26.12	24.70	23.29
11	32.18	30.77	29.35	27.94	26.52	25.10	23.69	22.27	20.86
12	30.33	28.92	27.50	26.09	24.67	23.26	21.84	20.43	19.01
13	28.90	27.48	26.07	24.65	23.24	21.82	20.40	18.99	17.57
14	27.75	26.34	24.92	23.51	22.09	20.68	19.26	17.85	16.43
15	26.83	25.42	24.00	22.59	21.17	19.76	18.34	16.93	15.51
16	26.08	24.67	23.25	21.84	20.42	19.01	17.59	16.18	14.76
17	25.46	24.04	22.63	21.21	19.80	18.38	16.97	15.55	14.14
18	24.93	23.52	22.10	20.69	19.27	17.86	16.44	15.03	13.61
19	24.49	23.08	21.66	20.25	18.83	17.42	16.00	14.59	13.17
20	24.11	22.70	21.28	19.87	18.45	17.04	15.62	14.21	12.79
21	23.79	22.37	20.96	19.54	18.13	16.71	15.30	13.88	12.47
22	23.51	22.09	20.68	19.26	17.85	16.43	15.02	13.60	12.19
23	23.26	21.85	20.43	19.02	17.60	16.18	14.77	13.35	11.94
24	23.04	21.63	20.21	18.80	17.38	15.97	14.55	13.14	11.72
25	22.85	21.44	20.02	18.61	17.19	15.78	14.36	12.95	11.53
26	22.69	21.27	19.85	18.44	17.02	15.61	14.19	12.78	11.36
27	22.53	21.12	19.70	18.29	16.87	15.46	14.04	12.63	11.21
28	22.40	20.98	19.57	18.15	16.74	15.32	13.91	12.49	11.08
29	22.28	20.86	19.45	18.03	16.62	15.20	13.79	12.37	10.96
30	22.17	20.75	19.34	17.92	16.51	15.09	13.68	12.26	10.85
31	22.07	20.66	19.24	17.83	16.41	15.00	13.58	12.17	10.75
32	21.98	20.57	19.15	17.74	16.32	14.91	13.49	12.08	10.66
33	21.90	20.48	19.07	17.65	16.24	14.82	13.41	11.99	10.58
34	21.83	20.41	19.00	17.58	16.17	14.75	13.33	11.92	10.50
35	21.76	20.34	18.93	17.51	16.10	14.68	13.27	11.85	10.44
36	21.69	20.28	18.86	17.45	16.03	14.62	13.20	11.79	10.37
37	21.64	20.22	18.81	17.39	15.98	14.56	13.15	11.73	10.32
38	21.58	20.17	18.75	17.34	15.92	14.51	13.09	11.68	10.26
39	21.54	20.12	18.70	17.29	15.87	14.46	13.04	11.63	10.21
40	21.49	20.07	18.66	17.24	15.83	14.41	13.00	11.58	10.17

Shaded area indicates limits of basic data.

Table 14.—Tree sawing time in minutes per Mbf.

(mill has resaw; scaling defect > 25%)

dbh	Merchantable height								
	1.0 log	1.5 log	2.0 log	2.5 log	3.0 log	3.5 log	4.0 log	4.5 log	5.0 log
10	45.28	43.86	42.45	41.03	39.62	38.20	36.79	35.37	33.96
11	42.85	41.43	40.02	38.60	37.19	35.77	34.36	32.94	31.53
12	41.00	39.59	38.17	36.76	35.34	33.93	32.51	31.10	29.68
13	39.56	38.15	36.73	35.32	33.90	32.49	31.07	29.66	28.24
14	38.42	37.01	35.59	34.18	32.76	31.35	29.93	28.52	27.10
15	37.50	36.09	34.67	33.26	31.84	30.43	29.01	27.60	26.18
16	36.75	35.34	33.92	32.50	31.09	29.67	28.26	26.84	25.43
17	36.13	34.71	33.30	31.88	30.47	29.05	27.64	26.22	24.80
18	35.60	34.19	32.77	31.36	29.94	28.53	27.11	25.70	24.28
19	35.16	33.75	32.33	30.91	29.50	28.08	26.67	25.25	23.84
20	34.78	33.37	31.95	30.54	29.12	27.71	26.29	24.88	23.46
21	34.46	33.04	31.63	30.21	28.80	27.38	25.97	24.55	23.14
22	34.18	32.76	31.34	29.93	28.51	27.10	25.68	24.27	22.85
23	33.93	32.51	31.10	29.68	28.27	26.85	25.44	24.02	22.61
24	33.71	32.30	30.88	29.47	28.05	26.64	25.22	23.81	22.39
25	33.52	32.11	30.69	29.28	27.86	26.45	25.03	23.62	22.20
26	33.35	31.94	30.52	29.11	27.69	26.28	24.86	23.45	22.03
27	33.20	31.79	30.37	28.96	27.54	26.13	24.71	23.30	21.88
28	33.07	31.65	30.24	28.82	27.41	25.99	24.58	23.16	21.75
29	32.95	31.53	30.12	28.70	27.29	25.87	24.46	23.04	21.63
30	32.84	31.42	30.01	28.59	27.18	25.76	24.35	22.93	21.52
31	32.74	31.32	29.91	28.49	27.08	25.66	24.25	22.83	21.42
32	32.65	31.24	29.82	28.40	26.99	25.57	24.16	22.74	21.33
33	32.57	31.15	29.74	28.32	26.91	25.49	24.08	22.66	21.25
34	32.49	31.08	29.66	28.25	26.83	25.42	24.00	22.59	21.17
35	32.43	31.01	29.60	28.18	26.77	25.35	23.94	22.52	21.11
36	32.36	30.95	29.53	28.12	26.70	25.29	23.87	22.46	21.04
37	32.31	30.89	29.48	28.06	26.65	25.23	23.82	22.40	20.98
38	32.25	30.84	29.42	28.01	26.59	25.18	23.76	22.35	20.93
39	32.20	30.79	29.37	27.96	26.54	25.13	23.71	22.30	20.88
40	32.16	30.74	29.33	27.91	26.50	25.08	23.67	22.25	20.84

Shaded area indicates limits of basic data.

Table 15.—Tree sawing time in minutes per Mbf.

(no resaw; scaling defect < 25%)

dbh	Merchantable height								
	1.0 log	1.5 log	2.0 log	2.5 log	3.0 log	3.5 log	4.0 log	4.5 log	5.0 log
10	68.48	67.06	65.65	64.23	62.82	61.40	59.99	58.57	57.16
11	61.97	60.55	59.14	57.72	56.31	54.89	53.48	52.06	50.65
12	57.02	55.60	54.19	52.77	51.36	49.94	48.53	47.11	45.70
13	53.16	51.75	50.33	48.92	47.50	46.09	44.67	43.26	41.84
14	50.11	48.69	47.28	45.86	44.45	43.03	41.62	40.20	38.78
15	47.64	46.22	44.81	43.39	41.98	40.56	39.15	37.73	36.32
16	45.62	44.21	42.79	41.38	39.96	38.54	37.13	35.71	34.30
17	43.95	42.53	41.12	39.70	38.29	36.87	35.46	34.04	32.63
18	42.55	41.13	39.72	38.30	36.88	35.47	34.05	32.64	31.22
19	41.36	39.94	38.53	37.11	35.70	34.28	32.87	31.45	30.04
20	40.35	38.93	37.52	36.10	34.69	33.27	31.85	30.44	29.02
21	39.47	38.06	36.64	35.23	33.81	32.40	30.98	29.57	28.15
22	38.72	37.30	35.89	34.47	33.06	31.64	30.23	28.81	27.40
23	38.06	36.64	35.23	33.81	32.40	30.98	29.57	28.15	26.74
24	37.48	36.07	34.65	33.23	31.82	30.40	28.99	27.57	26.16
25	36.97	35.55	34.14	32.72	31.31	29.89	28.48	27.06	25.65
26	36.52	35.10	33.69	32.27	30.86	29.44	28.03	26.61	25.20
27	36.11	34.70	33.28	31.87	30.45	29.04	27.62	26.21	24.79
28	35.75	34.34	32.92	31.51	30.09	28.68	27.26	25.85	24.43
29	35.43	34.01	32.60	31.18	29.77	28.35	26.94	25.52	24.11
30	35.14	33.72	32.31	30.89	29.48	28.06	26.65	25.23	23.81
31	34.87	33.46	32.04	30.63	29.21	27.80	26.38	24.97	23.55
32	34.63	33.22	31.80	30.39	28.97	27.56	26.14	24.73	23.31
33	34.41	33.00	31.58	30.17	28.75	27.34	25.92	24.51	23.09
34	34.21	32.80	31.38	29.97	28.55	27.14	25.72	24.31	22.89
35	34.03	32.62	31.20	29.78	28.37	26.95	25.54	24.12	22.71
36	33.86	32.45	31.03	29.62	28.20	26.79	25.37	23.96	22.54
37	33.71	32.29	30.88	29.46	28.05	26.63	25.22	23.80	22.39
38	33.57	32.15	30.74	29.32	27.91	26.49	25.08	23.66	22.24
39	33.43	32.02	30.60	29.19	27.77	26.36	24.94	23.53	22.11
40	33.31	31.90	30.48	29.07	27.65	26.24	24.82	23.41	21.99

Shaded area indicates limits of basic data.

Table 16.—Tree sawing time in minutes per Mbf.

(no resaw; scaling defect > 25%)

dbh	Merchantable height								
	1.0 log	1.5 log	2.0 log	2.5 log	3.0 log	3.5 log	4.0 log	4.5 log	5.0 log
10	79.15	77.73	76.32	74.90	73.49	72.07	70.66	69.24	67.83
11	72.64	71.22	69.81	68.39	66.98	65.56	64.15	62.73	61.32
12	67.69	66.27	64.86	63.44	62.02	60.61	59.19	57.78	56.36
13	63.83	62.42	61.00	59.59	58.17	56.76	55.34	53.93	52.51
14	60.77	59.36	57.94	56.53	55.11	53.70	52.28	50.87	49.45
15	58.31	56.89	55.48	54.06	52.65	51.23	49.82	48.40	46.99
16	56.29	54.87	53.46	52.04	50.63	49.21	47.80	46.38	44.97
17	54.62	53.20	51.79	50.37	48.96	47.54	46.13	44.71	43.30
18	53.21	51.80	50.38	48.97	47.55	46.14	44.72	43.31	41.89
19	52.03	50.61	49.20	47.78	46.37	44.95	43.54	42.12	40.71
20	51.01	49.60	48.18	46.77	45.35	43.94	42.52	41.11	39.69
21	50.14	48.73	47.31	45.90	44.48	43.07	41.65	40.24	38.82
22	49.39	47.97	46.56	45.14	43.73	42.31	40.90	39.48	38.07
23	48.73	47.31	45.90	44.48	43.07	41.65	40.24	38.82	37.41
24	48.15	46.73	45.32	43.90	42.49	41.07	39.66	38.24	36.83
25	47.64	46.22	44.81	43.39	41.98	40.56	39.15	37.73	36.32
26	47.19	45.77	44.36	42.94	41.53	40.11	38.69	37.28	35.86
27	46.78	45.37	43.95	42.54	41.12	39.71	38.29	36.88	35.46
28	46.42	45.01	43.59	42.18	40.76	39.35	37.93	36.52	35.10
29	46.10	44.68	43.27	41.85	40.44	39.02	37.61	36.19	34.78
30	45.80	44.39	42.97	41.56	40.14	38.73	37.31	35.90	34.48
31	45.54	44.12	42.71	41.29	39.88	38.46	37.05	35.63	34.22
32	45.30	43.88	42.47	41.05	39.64	38.22	36.81	35.39	33.98
33	45.08	43.67	42.25	40.84	39.42	38.01	36.59	35.18	33.76
34	44.88	43.47	42.05	40.64	39.22	37.81	36.39	34.98	33.56
35	44.70	43.28	41.87	40.45	39.04	37.62	36.21	34.79	33.38
36	44.53	43.12	41.70	40.29	38.87	37.46	36.04	34.63	33.21
37	44.38	42.96	41.55	40.13	38.72	37.30	35.89	34.47	33.06
38	44.23	42.82	41.40	39.99	38.57	37.16	35.74	34.33	32.91
39	44.10	42.69	41.27	39.86	38.44	37.03	35.61	34.20	32.78
40	43.98	42.57	41.15	39.74	38.32	36.91	35.49	34.08	32.66

Shaded area indicates limits of basic data.

Rast, Everette D.
1974. **Log and tree sawing times for hardwood mills.**
NE. Forest Exp. Sta., Upper Darby, Pa.
10 p. (USDA Forest Serv. Res. Pap. NE-304)

Data on 6,850 logs and 1,181 trees were analyzed to predict sawing times. For both logs and trees, regression equations were derived that express (in minutes) sawing time per log or tree and per Mbf. For trees, merchantable height is expressed in number of logs as well as in feet. One of the major uses for the tables of average sawing times is as a bench mark against which individual mills can make comparisons.

832.15 : 176.1

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a way to increase lumber grade yield and mill profits

by Neil K. Huyler

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MANUSCRIPT RECEIVED FOR PUBLICATION 11 MARCH 1974

LIVE-SAWING:

a way to increase lumber grade yield and mill profits

ABSTRACT

A study to compare live-sawing with conventional grade-sawing of factory-grade 3 red oak sawlogs revealed that live-sawing results in substantial increases in production rate, overrun, log value per thousand board feet, and significant reduction in size of the break-even log diameter.

LIVE-SAWING

APPLICATION

SAY THAT YOU are the operator of a sawmill, and you handle a lot of low-grade hardwood logs. How can you cut production costs and boost your profits? One way is by live-sawing the low-grade logs.

In a study in West Virginia, we compared live-sawing with conventional grade-sawing of factory-grade 3 red oak sawlogs. We found that live-sawing increased the production rate, increased overrun, and increased the log value per thousand board feet.

LIVE-SAWING

Here's how this method of live-sawing works.

Place the straight or nearly straight log on the carriage with the best face toward the saw. Use full taper set-out. Cut 4/4 boards till you reach the center of the log. Then turn the log 180 degrees and continue sawing the rest of the log through and through.

In this kind of sawing, you need to turn the log only once.

The occasional crooked or sweepy log will have to be turned twice. First saw a slab off one face. Turn the log 90 degrees to place the flat face against the headblocks. Then saw in the same way you sawed the straight logs.

The great advantage of this method of sawing is that you need to turn the log only once or twice. In grade-sawing, you have to turn the log at least three times.

POINTS TO WATCH

- For accurate live-sawing, the carriage should have tong dogs or some other type of dogs that hold the log securely against the carriage knees.
- Live-sawing produces a high percentage of quarter-sawed boards, and boards with heartwood centers and sapwood edges. This may cause greater than normal degrade losses during air-drying and kiln-drying.
- Much of the responsibility for lumber-grade recovery is shifted from the sawyer to the edgerman; so the edgerman should have a sound knowledge of hardwood lumber grading rules.
- Do not live-saw logs with unsound centers or logs with excessive crook or sweep. Both volume and grade are reduced in live-sawing such logs.
- Adjust the material-flow system in your mill so you can dispose of edgings quickly. This could be a problem with live-sawing.

For more detailed information about live-sawing and our study of it, see the following pages.

LIVE-SAWING

DOCUMENTATION

A MAJOR PROBLEM for the hardwood sawmill operator is to convert small low-grade logs into lumber at a profit. This problem is aggravated by a steady increase in the number of low-grade sawlogs received by sawmills, increasing lumber-production costs, and relatively constant lumber prices—especially for No. 2 and No. 3 common lumber. Since most sawmill operators have little or no control over timber quality and lumber prices, their best opportunity for increasing profits from small low-grade logs is to process the logs more efficiently.

In a recent study, we compared live-sawing (through-and-through sawing) with conventional grade-sawing of small low-grade red oak logs. Live-sawing resulted in greater production rates, greater overrun, and higher lumber value.

STUDY METHODS

The study was conducted in southern West Virginia at an all-electric circular sawmill that has a production capacity of about 10,000 board feet of 4/4 lumber per 8-hour day. The major species sawed are red oak, yellow-poplar, and hard maple. The lumber is marketed primarily as furniture and flooring stock.

Mill equipment included a Corley No. 3 special headrig with automatic air carriage, a 56-inch inserted-tooth circular saw, a 27-inch Frick edger, and a Tower double-end trim saw. A blower system is used to transport dust from the edger and headsaw. To increase mill efficiency, a Hosmer debarker and a hydraulic log turner have been installed. (Mention of brand names should not be taken as an endorsement by the USDA Forest Service.)

Factory-grade 3 northern red oak logs (*Quercus rubra*) were selected randomly for the study. The logs were graded according to Forest Service standard log-grading specifications (*Ostrander et al. 1963*) and separated into two groups. Group 1 consisted of 90 logs that were live-sawed; group 2 consisted of 49 logs that were grade-sawed. All logs were scaled according to the Scribner decimal C log rule. Deductions from gross volume were made for sweep, crook, rot, and other scaling defects. (About 10 percent of the logs were below factory-grade 3.) Distribution of log diameters for both sawing methods are shown in figure 1.

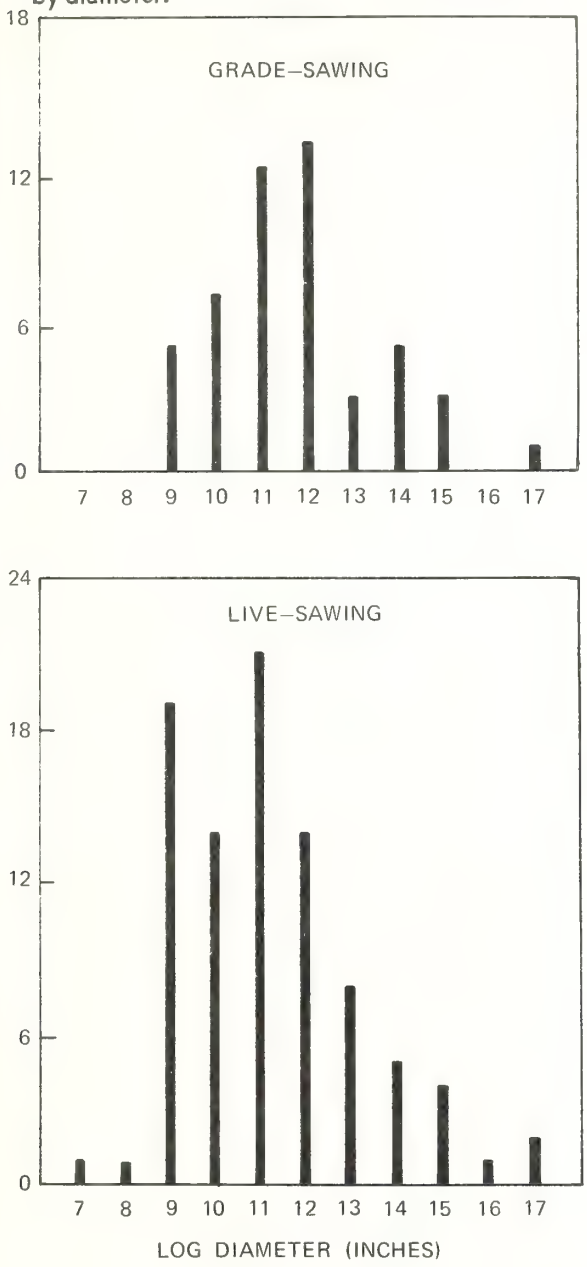
Sawing Techniques

Grade-sawing.—The log was positioned so that visible defects, primarily knots, were located on the edges of the sawing face (fig. 2). In most cases the poorest face (the face with the most defects) was sawed first, without using taper set-out. When the best face was sawed first, full taper set-out was used. Whenever the grade of the face being sawed dropped below the potential grade of adjoining faces, the log was turned. Thus three or more turns were made in grade-sawing a log.

Live-sawing.—Straight or nearly straight logs were positioned on the carriage with the best face towards the saw, using full taper set-out; 4/4 boards were removed until the approximate center of the log was reached (fig. 2). The logs were then turned 180 degrees and sawed the rest of the way through. Thus, each log was turned only once. For a few logs containing sweep or crook, a slab was removed and the logs were turned to place the flat surface to the headblocks. The logs were then sawed in the same manner as straight logs. For those logs containing sweep or crook, two turns were required.

Headsaw time for each log was recorded to the nearest 0.1 minute. The number of saw cuts and turns were also recorded for each log.

Figure 1.—Distribution of grade 3 log samples by diameter.



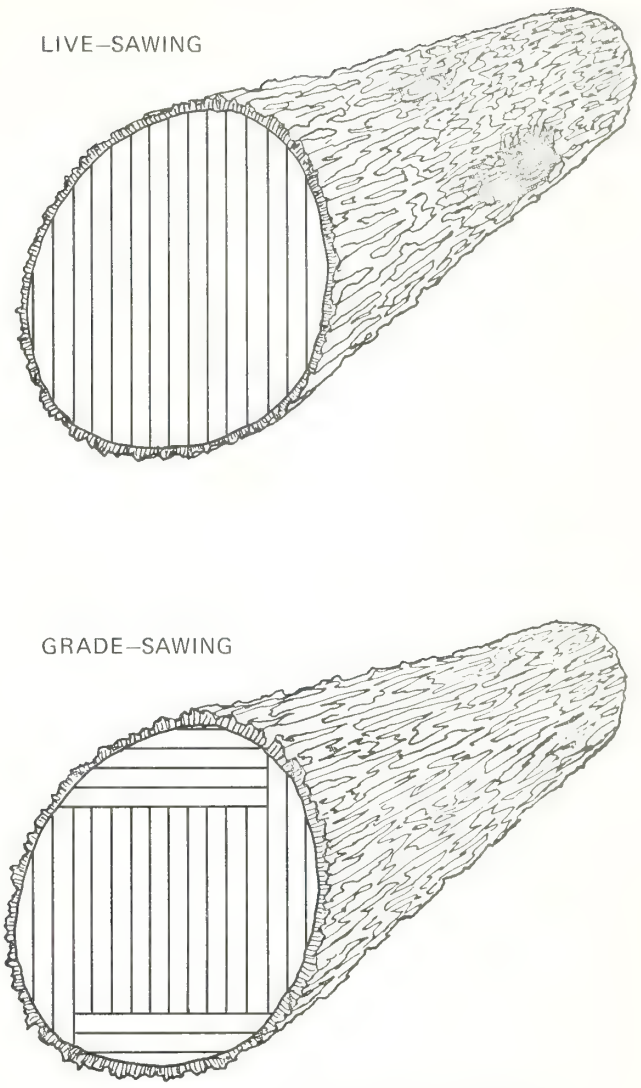


Figure 2.—Sawing patterns for live-sawing and grade-sawing.

Lumber Grade Recovery and Value Determination

The boards recovered from each sample log live-sawed were marked with the number of the parent log and tallied by grade and thickness according to National Hardwood Lumber Association Rules (*1969-70*). The air-dry lumber volume of each log was estimated by deducting 5 percent from the green volume. The value of lumber recovered for each log-diameter class was determined by applying current market prices (*Hardwood Market Report 1970*), by grade, to lumber yield for logs in the class. Overrun was computed as the difference between net log volume and air-dry lumber tally.

In the grade-sawing, lumber recovered from each log was tallied by board-foot volume only. This was done to determine production rates and overrun for the various diameters of logs used in grade-sawing. The lumber grade recovery for grade-sawing was not recorded because a review of lumber grade yield from past research at the study mill disclosed a close relationship between the mill's actual lumber grade yield and predicted yields published by the U.S. Forest Products Laboratory (*Paper FPL-63, 1966*) for logs of similar size. Therefore it was felt that accurate lumber grade yield predictions could be made from FPL Paper FPL-63.

The value of lumber produced in the grade-sawing was determined by multiplying the quality index log value for each log diameter as reported by McCauley and Mendel (*1969*) by the current market price of 4/4 No. 1 common lumber. This procedure was used because the quality index values were developed from the lumber grade yield estimates in FPL Paper FPL-63.

The actual percentage yields of the different grades of lumber recovered were computed for each log diameter for the live-sawing method. These yields were then compared with the percentage yields predicted for similar logs in FPL-63.

Analysis-of-variance techniques were used to determine whether differences in lumber grade yield between logs that were live-sawed and the lumber grade yield predicted in FPL-63 for similar logs were statistically significant.

Mill Production and Cost Determination

To standardize computations for both sawing methods, sawing time for each log (in minutes) was converted to sawing time per thousand board feet (M bd. ft.) air-dry lumber for the various diameter and length classes. Sawing time per M bd. ft. of lumber from logs of the same diameter and length was computed as the ratio of log sawing time to log volume, expressed in M bd. ft. Delay time was not considered in the computation. When a delay occurred while the log was being sawed, delay time was recorded and then subtracted from the total time to arrive at an actual sawing time. The sawing time per M bd. ft. for live-sawing was compared to that for grade-sawing to determine the relative lumber-production rates for the two sawing methods.

Sawing cost per M bd. ft. for both sawing methods was determined by multiplying the average time required to saw one M bd. ft. by the hourly cost values pertaining to the study mill. Costs of air-drying, selling, and indirect administrative cost were excluded from the analysis. A raw-material cost (log cost adjusted for overrun) of $45 per M bd. ft. Scribner decimal C log scale, was added to the sawing cost to determine the lumber-production cost. The lumber-production cost and lumber value (per M bd. ft. mill tally) were then analyzed to determine the break-even log diameter for both sawing methods.

RESULTS AND DISCUSSION

Lumber Grade Recovery

There was no significant difference (5-percent level) in the yields of First and Second (FAS) or First One Face (FIF) lumber between live-sawing and that predicted for grade-sawing. Also, diameter of the log had no effect on the yield of FAS or FIF lumber produced by either sawing method (table 1).

The effect of sawing method on the No. 1 common grade yield was highly significant (1-percent level). Live-sawing produced 8.1

Table 1.—Air-dry lumber yield for grade 3 red oak sawlogs, by sawing method

Sawing Method	Logs	Lumber grade						Volume
		FAS	FIF	1COM	2COM	3ACOM	3BCOM	
	No.	*——————Percent yield——————*						*Bd. ft.*
Grade-sawing[a]	90	0.2	0.6	14.0	22.2	15.4	47.6	4,757
Live-sawing[b]	90	.5	.9	8.4	41.8	34.5	13.8	4,814

[a] Percent yields predicted from FPL-63.
[b] Actual air-dry lumber yield from live-sawing.

Table 2.—Overrun and adjusted log cost[a] for grade 3 sawlogs, by diameter classes

Log diameter (inches)	Overrun (Scribner decimal C) live-sawed	Log cost per M bd. ft., mill tally	Overrun (Scribner decimal C) grade-sawed	Log cost per M bd. ft., mill tally
	Percent	*Dollars*	*Percent*	*Dollars*
8	16.1	38.76	14.5	39.30
9	13.9	39.51	11.4	40.39
10	11.7	40.29	8.2	41.59
11	9.5	41.10	5.1	42.82
12	7.3	41.93	2.0	44.12
13	5.1	42.82	— 1.2	45.55
14	2.9	43.73	— 4.3	47.02
15	.7	44.69	— 7.4	48.60
16	—1.4	45.64	—10.6	50.34
All diameters	7.3	41.93	2.0	44.12

[a] Assumed log cost of $45/M at the point of use.

percent No. 1 common lumber as compared to the 14.2 percent predicted yield for grade-sawing (table 1). Most of this difference in yield occurred in the 8- to 12-inch diameter logs because the opportunities to upgrade boards produced from small logs by ripping at the edger are negligible. But, with larger logs and wider boards, some No. 1 common can be ripped from the outer edges of the boards.

Sawing method also had a significant effect on the No. 2, 3A, and 3B common lumber yield. Live-sawing produced about 20 percent more No. 2 common, 19 percent more 3A common, but about 34 percent less No. 3B common than predicted for grade-sawing. In grade-sawing low-grade logs, the higher grades of lumber are cut from the outer portion of the log by turning several times; the remaining boxed heart yields a high percentage of No. 3B common lumber. In live-sawing, the higher quality outer portion of the log occurs on the edges of the middle boards, therefore upgrading the otherwise 3B common to No. 2 and No. 3A common.

Overrun

Live-sawing resulted in a 7.3-percent greater overrun based on the Scribner decimal C log rule (table 2). Greater overrun from live-sawing is attributed mainly to two factors: (1) less volume is lost to saw kerf, because fewer saw cuts are needed; (2) because the log is turned only once, volume loss due to slabbing is reduced. For 8- and 9-inch diameter logs, overrun for live-sawing was slightly greater than for grade-sawing. As log diameter increased above the 9-inch diameter class, live-sawing became progressively better than grade-sawing in terms of overrun, although overrun declined for both sawing methods as larger diameter logs were sawed (fig. 3).

Figure 3.—Percent overrun for grade 3 red oak sawlogs, by diameter.

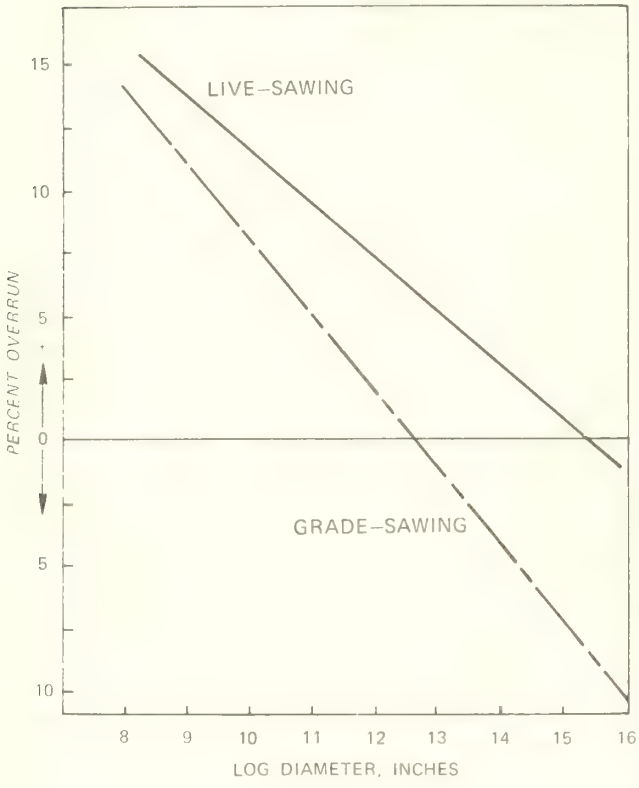
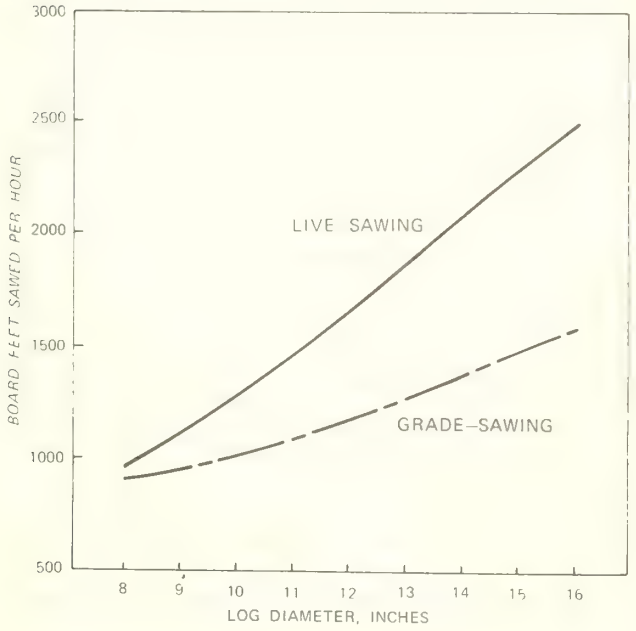


Figure 4.—Volume of factory-grade 3 sawlogs sawed per hour, by diameter: grade-sawing versus live-sawing.



Lumber-Production Rates

Lumber production rates in board feet per hour (mill tally basis) were nearly 41 percent greater for live-sawing than for grade-sawing (fig. 4). Headsaw time for live-sawing averaged 39.2 minutes per M bd. ft. as opposed to 51.7 minutes per M bd. ft. for grade-sawing.

The higher lumber-production rate per hour for live-sawing is the result of two factors: (1) logs were turned on the carriage only once; and (2) fewer sawcuts were required (table 3). To illustrate, at the study mill a log 12 inches in diameter and 12 feet long required about 0.08 minutes per turn and 0.16 minutes per sawcut for conversion to 4/4 lumber. Grade-sawing required at least 3 turns and 14 sawcuts; whereas live-sawing required only 1 turn and 9 sawcuts. Thus 2.48 minutes were required for conversion in grade-sawing, while live-sawing required only 1.52 minutes.

Mill Profit

There are three ways in which a mill operator can increase his profit: (1) lower sawing cost per unit by increasing the production rate; (2) increase the value of the product by increasing the volume yield (increased overrun) or increasing the yield of higher lumber grades; (3) and some combination of (1) and (2).

Live-sawing increased both production rate and overrun. But to fully judge these two factors, we must look at how live-sawing affects lumber values and the cost of lumber production.

Sawing cost per M bd. ft. decreased for both sawing methods as log diameter and length increased. However, sawing cost by live-sawing averaged $30.03 per M bd. ft. while that for grade-sawing averaged about $34.59 per M bd. ft. Thus live-sawing reduced the sawing cost by $4.56 per M bd. ft., or about 12 percent (table 4).

To arrive at a total lumber-production cost, a log cost of $45 per M bd. ft. (adjusted for overrun) was added to the sawing cost. The total lumber-production cost for live-sawing average $71.96 per M bd. ft. as compared with $78.71 per M bd. ft. for grade-sawing (table 4). Therefore, an overall reduction in

Table 3.—Average number of sawcuts and turns for two sawing methods

Sawing method	Logs	Average log diameter	Average length	Average number of sawcuts	Average number of turns
	No.	*Inches*	*Feet*	*No.*	*No.*
Grade-sawing	49	11.8	11.3	14	3
Live-sawing	90	11.2	12.3	9	1

Table 4.—Contrasted live-sawing and grade-sawing production costs per M board feet for grade 3 sawlogs

Log diameter (inches)	Log cost per M bd. ft.		Milling cost per M bd. ft.		Total cost per M bd. ft.	
	Live-sawing	Grade-sawing	Live-sawing	Grade-sawing	Live-sawing	Grade-sawing
8	$38.76	$39.30	$37.55	$39.01	$76.31	$78.31
9	39.51	40.39	35.28	37.91	74.79	78.30
10	40.29	41.59	33.28	36.80	73.57	78.39
11	41.10	42.82	31.52	35.70	72.62	78.52
12	41.93	44.12	30.03	34.59	71.96	78.71
13	42.82	45.55	28.78	33.49	71.60	79.04
14	43.73	47.02	27.79	32.39	71.52	79.41
15	44.69	48.60	27.05	31.28	71.74	79.88
16	45.64	50.34	26.54	30.18	72.18	80.52
Average, all diameters	$41.93	$44.12	$30.03	$34.59	$71.96	$78.71

Table 5.—Log values[a] per M board feet for live-sawing vs. grade-sawing

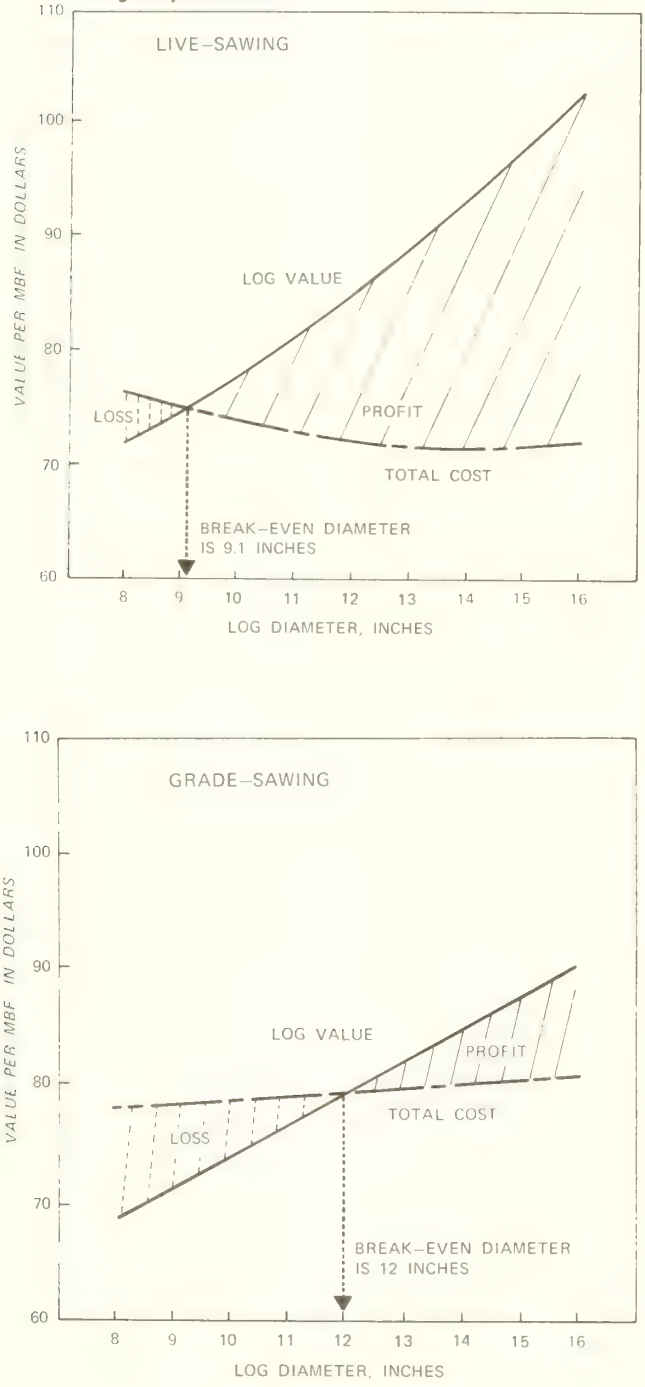
Log diameter (inches)	Value/M bd. ft. live-sawing	Value/M bd. ft. grade-sawing	Difference per M bd. ft.	Increase
	Dollars	*Dollars*	*Dollars*	*Percent*
8	$ 71.95	$69.13	$ 2.82	4.1
9	74.43	71.90	2.53	3.5
10	77.31	74.38	2.93	3.9
11	80.59	76.87	3.72	4.8
12	84.27	79.35	4.92	6.2
13	88.35	81.83	6.52	8.0
14	92.83	84.46	8.37	9.9
15	97.71	86.80	10.91	12.6
16	102.29	89.15	13.41	14.7
Average, all diameters	$ 85.52	$79.32	$ 6.21	7.8

[a] Air-dry lumber prices per M bd. ft. FAS—$245, No. 1 common—$138, No. 2 common—$85, No. 3A common—$75, No. 3B common—$40.

total production cost of $6.75 per M bd. ft., or about 9 percent, was realized from live-sawing.

In addition to the reduction in total lumber-production cost per M bd. ft., live-sawing increased the value of lumber produced by 7.8 percent over grade-sawing. The average value of live-sawed lumber was $85.52 per M bd. ft., and the comparable value for grade-sawing was $79.32 per M bd. ft. (table 5). This increase is a direct result of live-sawing producing more No. 2 and 3A common lumber, less No. 3B common lumber, and more overrun

Figure 5.—Log value and total production cost per M board feet for live-sawing (top) and grade-sawing (bottom) factory-grade 3 sawlogs, by diameter.



than grade-sawing. These factors more than offset the greater amounts of No. 1 common lumber produced by grade-sawing.

The effects of reduced lumber-production cost per M bd. ft. and increased value of lumber produced per M bd. ft. is substantial for live-sawing. The overall gain for live-sawing exceeded $13 per M bd. ft. This means that the study mill, which has a production of about 10 M bd. ft. per day, could increase mill profit by as much as $130 a day if the grade 3 logs were live-sawed rather than grade-sawed.

Perhaps more important is how live-sawing affects the size of the break-even log. A graphic comparison of total lumber-production cost and average lumber value by log diameter shows how the break-even or zero-profit log diameter can be determined for both methods of sawing. The diameter of the break-even log for live-sawing is 9.1 inches as compared with 12.0 inches for grade-sawing (fig. 5). Thus live-sawing actually permits the profitable manufacture of smaller diameter grade 3 red oak logs than does the more conventional grade-sawing. Also, the profit margins are progressively greater for live-sawing as log diameter increases above the break-even point (table 6).

CONCLUSIONS

In this study, live-sawing factory-grade 3 red oak logs resulted in significant gains over grade-sawing in lumber-production rates (40.7 percent), decreases in the yield of No. 3B common lumber, more overrun, an increase in average lumber value (7.8 percent), and a reduction in size of the break-even log. Although live-sawing produced less No. 1 common and better lumber than grade-sawing, the added overrun, the increased production, and the reduction in yield of No. 3B common lumber more than offset the loss of high-grade lumber.

The live-sawing method can be adopted by the sawmill industry without major changes in mill layout or expenditures in capital equipment. A mill operator who must gain mill efficiency to cope with the increase in the ratio of low-grade to high-grade logs should consider live-sawing.

Although these results are based on operat-

Table 6.—Margin of profit for live-sawing versus grade-sawing factory grade 3 red oak sawlogs, by log diameter

Log diameter (inches)	Production cost per M bd. ft.		Lumber value per M bd. ft.		Profit margin per M bd. ft.	
	Live-sawing	Grade-sawing	Live-sawing	Grade-sawing	Live-sawing	Grade-sawing
8	$76.31	$78.31	$71.95	$69.13	$—4.36	$—9.18
9	74.79	78.30	74.43	71.90	—0.36	—6.40
10	73.57	78.39	77.31	74.38	3.74	—4.01
11	72.62	78.52	80.59	76.87	7.97	—1.65
12	71.96	78.71	84.27	79.35	12.31	0.64
13	71.60	79.04	88.35	81.83	16.75	2.79
14	71.52	79.41	92.83	84.46	21.31	5.05
15	71.74	79.88	97.71	86.80	25.97	6.92
16	72.18	80.52	102.29	89.15	30.11	8.63
Average, all diameters	$71.86	$78.71	$ 85.52	$79.32	$13.66	$0.61

ing conditions at one study mill, they should prove generally applicable to most other operations using a single circular headsaw without resaw equipment. However, consider the following before adopting the live-sawing method:

- For accurate live-sawing, the mill carriage should have tong dogs or some other type of dogs that grip the log or cant securely on both edges and hold it tightly against the knees of the carriage.
- The live-sawing method produces a high percentage of quarter-sawed lumber and boards with heartwood centers and sapwood edges. Thus higher than normal degrade losses may be experienced in air-drying or kiln-drying this lumber.
- Much of the responsibility for lumber grade recovery is shifted from the sawyer to the edgerman. Therefore, the latter should have a sound knowledge of hardwood lumber-grading rules.
- Logs with unsound centers or excessive crook or sweep should not be live-sawed. Both lumber volume and grade yield are reduced greatly by live-sawing such logs.
- The material flow system in the mill should permit edgings to be disposed of quickly. Although this was not a problem in the study mill, it is conceivable that problems could arise from disposal of edging materials.

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9 p., illus. (USDA For. Serv. Res. Pap. NE-305)

A study to compare live-sawing with conventional grade-sawing of factory-grade 3 red oak sawlogs revealed that live-sawing results in substantial increases in production rate, overrun, log value per thousand board feet, and significant reduction in size of the break-even log diameter.

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Effects of Defoliation, Girdling, and Severing of Sugar Maple Trees on Root Starch and Sugar Levels

USDA FOREST SERVICE RESEARCH PAPER NE-306
1974

NORTHEASTERN FOREST EXPERIMENT STATION
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MANUSCRIPT RECEIVED FOR PUBLICATION 29 JULY 1974

Effects of Defoliation, Girdling, and Severing of Sugar Maple Trees on Root Starch and Sugar Levels

ABSTRACT

Root starch levels of defoliated sugar maple trees, on the average, were lower after 4 weeks in two separate experiments than in girdled, cut off, or girdled and defoliated trees. Root starch levels in all these treatments were lower than in controls. Sucrose levels, but not the levels of fructose and glucose, followed the same trends. It is suggested that carbohydrates are moved upward in the phloem of the stem and to a lesser extent in the xylem in defoliated trees, and that this accounts for the relatively low levels of starch and sucrose in these trees' roots.

INTRODUCTION

DEFOLIATION of sugar maple (*Acer saccharum* Marsh.) trees would be expected to cause a decline in root starch. Experiments show that this occurs within 2 to 3 weeks after complete defoliation (*Parker and Houston 1971, Wargo 1972*). It might seem that this is simply a case of starvation, but the situation may be more complex. Mobilization of food reserves similar to that during spring changes may occur. Leaf removal may elicit the translocation of hormones or metabolites in the stems (*Kozlowski 1971*). When refoliation follows defoliation, root reserves are more sharply depleted than when refoliation does not occur (*Wargo et al. 1972*). Interruption of stem translocation with and without defoliation should help to clarify the mechanisms that bring about starch hydrolysis in roots of defoliated trees. This paper reports results of studies in two different years on the effects of several such treatments on starch and sugar levels in sugar maple roots.

METHODS AND MATERIALS

Fifty saplings about 10 m tall and 3 to 6 cm dbh were selected for the 1971 experiment in southern Connecticut. Randomly selected groups of 10 trees were defoliated, girdled, girdled and defoliated, or cut off on June 7. Ten untreated trees served as controls.

Defoliation consisted of bending trees down and plucking off all the leaves, not including petioles, by hand. Girdling was done with a knife at breast height so that a band of bark 3 cm wide was removed all around the tree into the cambium. Cutting off was done by severing the tree 1 m above-ground. After 2 weeks, root systems of half of the trees of each group were excavated and about 30 seg-

ments 10 cm long and 1 cm thick were collected. The remaining trees were harvested after 4 weeks.

The experiment was repeated in 1972 in a different location, again beginning on June 7. This experiment, conducted to confirm the results of 1971, utilized only 25 trees and all were harvested after 4 weeks. The 1971 growing season from mid-June to mid-July was unusually dry compared to 1972, when frequent rains occurred in the same period.

Root samples were brought to the laboratory within 30 minutes and were frozen and stored at —35°C. From the 30 samples per tree, three were taken randomly and two sections were made from each of the three. A freehand cross section, approximately 25 μ thick was stained with I_2-KI for 10 minutes and examined at 100 and 660X *(Parker 1970)*. Three rows of 10 cells each, running tangentially across rays, were examined. The number of cells with starch grains found per row was expressed as a number from 0 to 10. Counts were averaged for the three rows of cells, for the two sections per root, and for the three roots per tree. Since large numbers of specialized starch-containing fiber tracheids occur in sugar maple roots *(Parker 1974)*, it is not unusual to obtain counts of 8 or even 9 in healthy, untreated trees. Because of the variation of scores within each root, counts were classified into four categories: 0 to 1, depleted; 1 to 3, low; 3 to 5, medium; and 5 to 9, high. These four categories correspond closely to those used by Wargo *(1974)*, based on a visual assessment of I_2-KI staining without optical aid.

Sugars were determined as follows: From each seedling 3 segments of root, including bark and wood, totalling 5 g were cut into 3 mm pieces with pruning shears, ground in a Waring blendor with 100 ml of 80 per cent ethanol, and filtered under suction through Whatman #1 paper. Other pieces from the same roots were weighed, dried in an oven at 105°C for 24 hours, and reweighed to estimate dry weight. The filter cake was washed with another 50 ml of 80 per cent ethanol and the liquid filtrates combined and evaporated under an air stream to 15 ml. Three 5-lambda drops of the concentrated extract were put on Whatman #1 papers, 23 x 57 cm, and developed descending in n-butanol, water, and acetic acid 4:5:1. Anisidine and benzidine sprays were used to visualize sugars *(Stange 1959, Parker 1962)*. The density of the visualized sugar spots was compared to that of standards on the same papers using a densitometer with integrator.

Sugar levels were expressed as a percentage of dry weight and are an average of five trees.

RESULTS

Starch

Two weeks after the start of the 1971 experiment, the average root starch of treated trees was slightly lower than that of controls. There were, however, no real differences among treatments, and the data are not presented here.

After 4 weeks in both years, the average root starch of defoliated trees was depleted, whereas that of girdled, girdled and defoliated, or cut-off trees was either low or medium (table 1). There were also differences

Table 1.—Starch and sucrose levels in roots of experimentally treated sugar maples.

Experiment	Controls	Cut off	Girdled	Girdled-defoliated	Defoliated
			STARCH		
1971	High	Medium	Low	Low	Depleted
1972	High	Medium	Medium	Low	Depleted
			SUCROSE		
1971	0.15	0.12	0.12	0.17	0.09
1972	0.10	0.09	0.11	0.06	0.05

between trees that were cut off and those that were girdled and defoliated (table 1).

Sugars

Sucrose, glucose, and fructose were the only sugars that occurred in sufficient amounts for accurate quantification. Other sugars, when detected, occurred only in trace amounts and are not considered here.

After 4 weeks in both years, there were differences in sucrose among the various treatments (table 1). Trends in sucrose levels correspond rather closely to those of starch. Although an analysis of variance revealed no significant differences among treatments in either year, sucrose was lower in defoliated seedlings than in girdled, cut-off, or girdled and defoliated saplings, just as starch was. Levels of fructose and glucose did not differ appreciably among treatments.

DISCUSSION

Girdling of trees is known to result in some decline in starch in the roots *(Curtis 1935, Woods et al. 1959)*. Defoliation, too, as mentioned above, brings about root-starch depletion. The present research shows that total defoliation caused a greater depletion of root starch than girdling.

This might be explained by the fact that carbohydrates can move from the roots up the stem phloem of defoliated trees but are prevented from doing so in trees that have been girdled or severed. Some root starvation (net loss of food reserves) probably resulted from each of the treatments. Curtis's *(1935)* many experiments with girdling woody plants indicated that most upward carbohydrate movement occurred in the phloem and very little or none in the xylem. However, starch levels in trees that were girdled and defoliated were lower than in those cut off. This difference between two treatments in which the phloem was severed suggests that some upward movement of carbohydrates also occurred in the xylem.

The possibility that a hormone or metabolite produced in the twigs migrates downward to the roots and triggers starch hydrolysis cannot, of course, be proven or disproven by the data. Hydrolysis of starch to glucose can occur as a result of allosteric enzymes that are activated by a small quantity of end product; in this case, glucose *(Lehninger 1971)*. The concept of hormone production and transport would not, then, have to be invoked to explain the results of these experiments.

A loss in root starch and sucrose is associated with the spring bud burst *(Wargo 1971)*, but it is small compared to that following a June defoliation, which caused a sharp and nearly total loss *(Parker 1970, Wargo 1972)*. This difference in response suggests that refoliating twigs do not produce hormones which, when moved to the roots, cause starch hydrolysis. It is more likely that the twigs have already lost much of their reserves during the spring bud burst; then when a second bud burst occurs as a result of defoliation, a still greater demand is put on food reserves in various parts of the tree, including the roots.

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[416.11 + 413.2--176.1 *Acer saccharum* Marsh.] : 161.34

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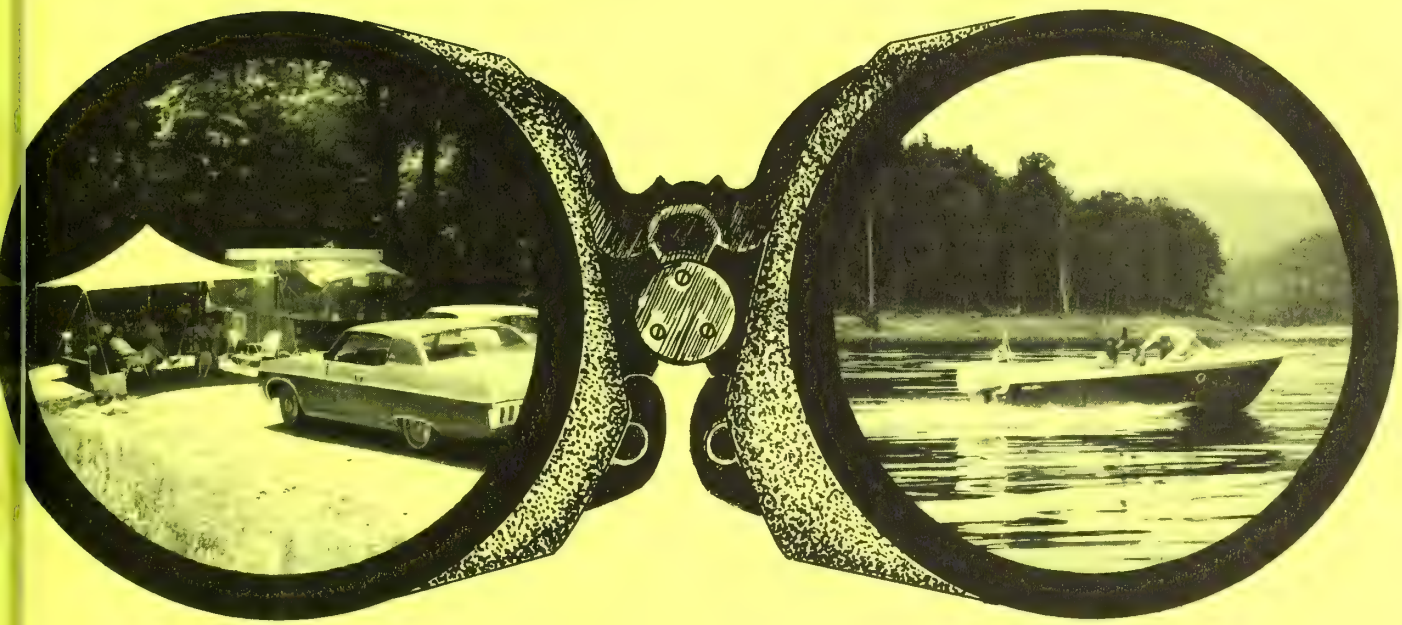

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The study reported here was carried out and funded as part of the graduate recreation studies program at the State University of New York College of Environmental Science and Forestry at Syracuse, N.Y.

MANUSCRIPT RECEIVED FOR PUBLICATION 2 APRIL 1974

Opinions of Campers and Boaters at the Allegheny Reservoir

by George H. Moeller
Rodney G. Larson
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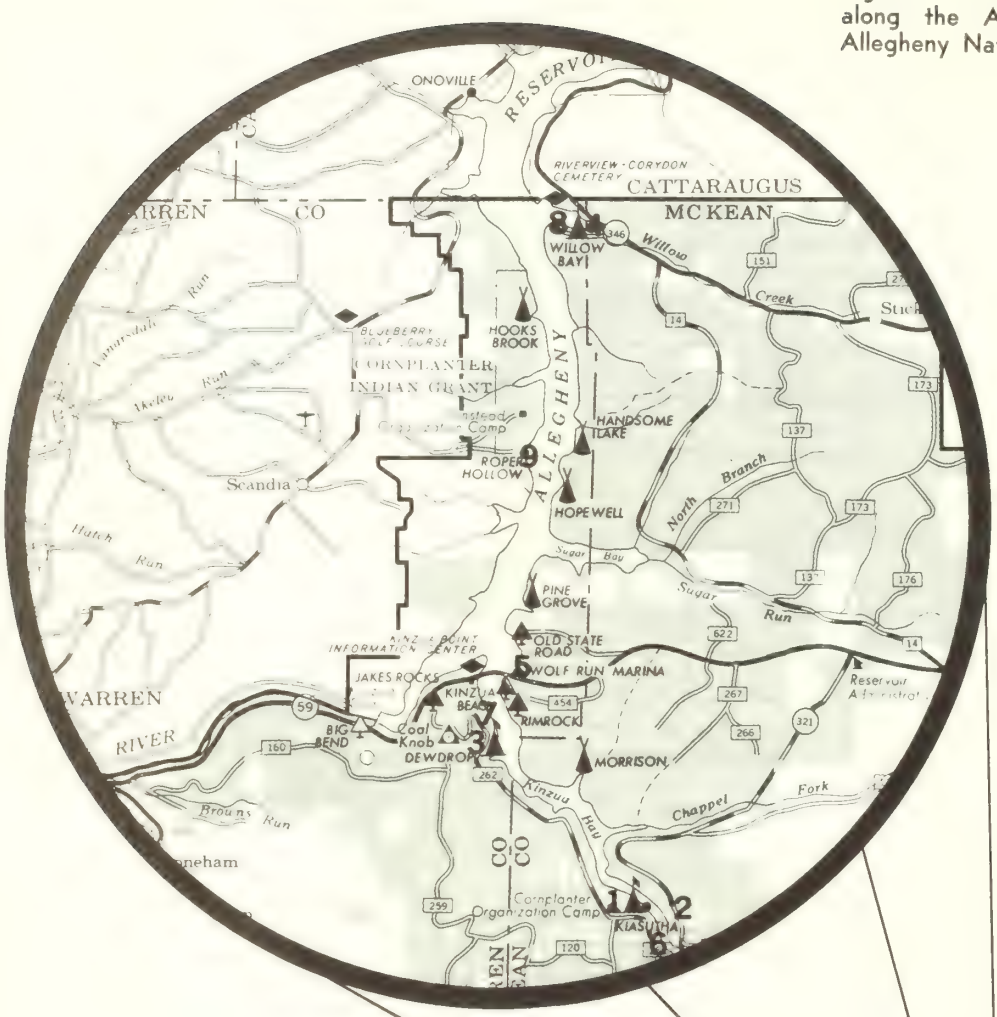
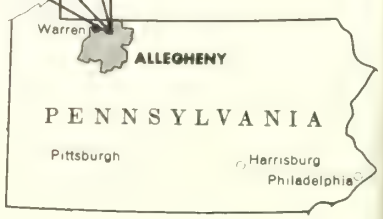
ABSTRACT

Interviews with 157 campers and 281 boaters near the Allegheny reservoir on the Allegheny National Forest revealed that their perceptions of management problems differed from those of managers. Different users had different attitudes toward recreation use controls, fee policies, recreation zoning, law enforcement, and facility development needs. This diversity indicates that changes in recreation management policy will not affect all recreation users equally; their impact will depend on how active the users are, the number of activities they participate in, and how familiar they are with the area.

Figure 1. — Sampling locations along the Allegheny Reservoir, Allegheny National Forest.





	Parties Sampled
CAMPGROUNDS	
1. Kiasutha	53
2. Red Bridge	30
3. Dew Drop	38
4. Willow Bay	15
Total	136
BOAT LAUNCH SITES	
5. Wolf Run Marina	60
6. Kiasutha	76
7. Dew Drop	53
8. Willow Bay	59
9. Roper Hollow	33
Total	281

THE STUDY PROBLEM

Recreation resource managers are confronted with the problem of managing fixed resources for growing recreation needs. Management programs must be developed to balance conflicting recreation demands equitably while, at the same time, maintaining the integrity of the natural resource.

Recreation management decisions continue to be made without adequate knowledge of the recreation user, his attitudes, and his opinions of management policies and problem solutions. Past research has shown that resource managers are not always able to perceive objectively management policies that are acceptable to recreation users *(Hendee and Harris 1970)*.

The purpose of this study was to provide resource managers and planners with information about the attitudes and opinions of recreation users. Interviews were conducted with campers and boaters near the Allegheny reservoir in the Allegheny National Forest, in northwestern Pennsylvania. The results of this study should provide recreation managers elsewhere with better information on which to base critical management decisions. Although some recreation management problems concern a particular area, many problems discussed in this study — overuse of facilities, control of resource use, law enforcement, facility development, and user fees—are common to other heavily used recreation areas.

THE STUDY AREA

The Kinzua Dam in northwestern Pennsylvania, 9.5 miles east of Warren, Pennsylvania, impounds the 12,080 acre Allegheny Reservoir, 7,634 acres of which are in Pennsylvania and the remainder in New York State. At normal summer pool, the reservoir is 27 miles long and has 91 miles of shoreline.

Most of the land around the Pennsylvania portion of the reservoir is administered by the U. S. Forest Service as part of the Allegheny National Forest. Others with vested management responsibilities include the U. S. Army Corps of Engineers, Seneca Nation of Indians, New York State Department of Environmental Conservation, Cattaragus County, New York, and various private landowners.

The Forest Service has developed 17 recreation areas on or directly adjacent to the reservoir. These provide for a wide range of recreational activities that include boating, swimming, camping, picnicking, and sightseeing. Information about facilities and services is provided through a centrally located Forest Service information center near the Kinzua Dam. The capacity of developed recreation facilities was increased from 2,480 people at one time in 1966 to 13,460 in 1972.

The Allegheny Reservoir has the potential to be a major recreation attraction. It is within 1 day's drive for over 80 million people (fig. 1). Since 1966, when the reservoir and recreation adjacent facilities opened, recreation use has increased from 91,900 to approximately 772,600 visitor-days per year.[1] Projections are that recreation use could reach 5 million visitor-days by the year 2000.[2]

[1] A visitor-day consists of 12 user-hours, which may be aggregated continuously, intermittently, or simultaneously by one or more persons.

[2] Projection obtained from 1972 Reservoir Management Plan. The possibility of reaching the projected level depends on many companion factors such as improved road systems, program funding, and recreation facility development by government and private interests.

STUDY METHOD

Visitors were sampled at four developed campgrounds and five boat-launching sites. They were selected on 20 randomly selected weekend days and eight weekdays during June, July, and August, 1971. The self-designated "head" of the camping group was interviewed for the study of campers (Appendix B). Boaters were contacted as they returned to launching sites. Interviewers briefly explained the purpose of the study and handed the person who was driving a questionnaire to be returned by mail (Appendix C). For non-power boats, the apparent "head" of the group was the respondent.

Interviews were allocated to recreation sites in approximate proportion to their use on the sampling day. A total of 157 campers and 281 boaters responded. Only two campers refused to participate in the study. An 89-percent response was obtained from boaters after one follow-up mailing of the questionnaire.

STUDY RESULTS

Respondent Profiles

A brief discussion of the characteristics of respondents will provide some background for the attitudes and opinions discussed later. More details are given in Appendix A. It should be recognized that the two groups surveyed were not mutually exclusive—that is, many campers boated and many boaters camped.

The average camper respondent was 42 years old and had a high school education. His $11,000 median annual family income exceeded the current national median by $500. Chances are even that he had camped on the Allegheny before the study. He had an average of 6 years total camping experience. His average investment in camping equipment—typically a tent or tent trailer—was $1,400. He traveled an average distance of 160 miles in 3 hours to reach the reservoir and stayed for 5 nights. His group typically included five people, husband, wife, and children. They participated in a wide variety of activities, with fishing and visiting scenic overlooks as the most common.

The average boater respondent was 41 years old and had 2 years of college. His $11,150 median annual family income exceeded the current national median by $650. He tended to work in a managerial or related occupation. Chances are four to one that he had previously boated on the Allegheny Reservoir. If so, he averaged 2.4 years of boating on the reservoir, and had spent 11 days boating on the reservoir in the year before the study. He averaged 8 years of total boating experience. Most typically he used a 16-foot boat powered by a 26- to 80-horsepower motor. His average investment in boating equipment was $2,500. He traveled an average distance of 78 miles in less than 2 hours to reach the reservoir. Chances are about even that he was also a camper. If so, he stayed an average of 4 nights. If he did not camp, he stayed on the water for an average of 5 hours. His group averaged 3.5 people, and chances were about even that it included children. In addition to pleasure boating, his most typical water activity was waterskiing, followed by fishing and swimming.

User Attitudes

What kinds of management problems do users perceive and which do they think are most important? How do users feel about current management? What are their opinions about management alternatives?

Most campers did not feel that facilities were overused. But they did see uncontrolled camping—camping in areas other than designated campgrounds—as a problem. Campers criticzed current management for not having better facilities, more specialized services, better information services, and site registration procedures. The majority of campers supported limiting the number of campers, opposed higher fees, felt camping should be allowed only in designated areas, and favored regular law enforcement with appropriate punishment for violators.

Most boaters did not view the reservoir as overused, nor did they recognize any major management problems. They did criticize current management for not enforcing

regulations, and saw a need for more launching sites, docks, campgrounds, and toilets. Their general reaction toward various management proposals was that zoning was not needed but that more boat patrols, along with appropriate punishment of violators, were needed. They were divided in their opinion of boat-launching fees.

Criticism of Current Management

A management problem common to many recreation sites is the excessive wear of facilities and vegetation caused by heavy use. But when users were asked whether they felt the reservoir area was "overused," only 34 percent of the campers and 15 percent of the boaters said yes. Yet the reservoir and surrounding facilities are used to overflow design capacity on most summer weekends.

Of those who considered overuse a problem, few related it to impact on natural conditions. Most found it difficult to define "overuse." A common definition referred to "overcrowded facilities." Only 1 out of 10 campers defined overuse in relation to damage to the natural environment. Boaters connected overuse with crowding at launching sites.

Campers

Three out of four campers expressed a concern for management of the Allegheny area. They were most concerned about the facilities and services available at campgrounds. Although the campgrounds used in the study are already highly developed, with flush toilets and showers, campers felt that electricity should be available and that concessions and firewood should be provided. Second in importance were questions of administration and management policy. Campers wanted more information and closer regulation through site registration. Campers showed little concern about management outside the immediate area where they were camping.

Overall, 6 out of 10 campers mentioned two or more problems related to management. But their amount of past camping experience in the Allegheny Reservoir area and the composition of the camping group were correlated with their reaction. Seventy-two percent of those who had camped in the area for 10 or more days in the previous year mentioned two or more management problems, as compared to 26 percent of those who had camped less than 9 days ($P < .001$).[3] Sixty percent of campers who had not camped on the reservoir during the previous year mentioned two or more problems.

Respondents from large groups and those in groups with larger numbers of children mentioned more problems. Fifty percent of the respondents from groups of four or fewer mentioned two or more problems, as compared to 70 percent from groups of five or more ($P < .05$). The number of children in the group, a closely correlated variable, showed a similar distribution, with 80 percent of the respondents from groups with four children or more suggesting at least two management problems, as compared to 47 percent for groups with three or fewer children ($P < .01$).

Boaters

Three out of four boaters felt that there was at least one problem in reservoir management. Their criticisms fell into three categories: reservoir water management, water facilities, and land facilities. The most frequently expressed concern about water management was the need for more patrols and better enforcement of regulations. On the water, boaters wanted more launching sites and docks; on land, more campgrounds and toilets were the needs most often mentioned.

Local boaters, those who traveled 25 miles or less to the reservoir, were more dissatisfied with reservoir management than other boaters. While 86 percent of local boaters registered at least one complaint, only 55 percent of those who traveled over 25 miles had a complaint ($P < .01$).

Other characteristics of the respondents that were correlated with their satisfaction with management were income and conservation group membership. Thirty percent of

[3] Chi-square level of significance.

boaters with family incomes less than $8,000 registered complete satisfaction, as compared to 16 percent with incomes in excess of $12,000 ($P < .10$). More boaters who were members of conservation groups were satisfied (34 percent) than boaters who were not members of conservation groups (22 percent) ($P < .10$).

The type of boating equipment used was also correlated with satisfaction. Boaters who used engines of 25 horsepower or less were significantly ($P < .01$) more satisfied (55 percent) than boaters who used 60 horsepower or larger engines (18 percent). A closely correlated variable, investment in boating equipment, showed a similar relationship, with satisfaction decreasing as investment increased.

Boaters who participated in land activities were significantly ($P < .05$) less satisfied (18 percent) than boaters who only boated (32 percent). The more familiar boaters were with the reservoir, the more likely they were to have a management complaint. Three in 10 of those who boated within 1 mile of launching sites were satisfied, as compared to 2 in 10 of those who traveled greater distances ($P < .10$).

Perception of Management Problems

Campers

Campers were asked to give their impressions of the severity of four management problems. In order of perceived importance, they were: uncontrolled camping, unsanitary conditions, destruction of vegetation, and littering.

Uncontrolled camping—camping in areas other than designated campgrounds — was seen as a problem by 6 out of 10 campers (fig. 2). But campers who traveled less than

Figure 2.—Aerial view of undesignated camping along reservoir shoreline. Such indiscriminate camping creates critical management problems of law enforcement, site degeneration, and sanitation.

100 miles to reach the reservoir were more likely (76 percent) to consider it a problem than campers who traveled 100 miles or more (42 percent) ($P < .05$). Responses also differed between respondents from small and large groups. While 70 percent of the campers from groups of four or fewer felt uncontrolled camping was a problem, only 46 percent of those from larger groups felt the same ($P < .10$).

Overall, one in three campers felt that unsanitary conditions were a problem in campgrounds. But among first-year campers, 2 in 10 felt that unsanitary conditions were a problem, as compared to 4 in 10 who had camped on the reservoir for two or more years ($P < .10$).

Destruction of vegetation in and around campgrounds was viewed as a problem by one out of four campers. But as camping experience increased, a greater proportion felt it was a problem—17 percent of first-time campers, compared to 54 percent of campers who had camped on the Allegheny before ($P < .05$).

Only one out of 10 campers perceived littering as a problem.

Boaters

Boaters were asked to estimate the severity of four problems. In order of perceived importance, they were: overcrowding, water pollution, lack of rule enforcement, and conflicting water uses. More than half of the boaters felt that none of these was a problem.

Overcrowding. — Thirty-seven percent of the boaters perceived overcrowding as a problem on the reservoir, and the more experience they had, the more likely they were to see it as a problem. Of local users, those who traveled 25 miles or less, 59 percent felt that crowding was a problem as compared to 20 percent of non-local users ($P < .001$). While 16 percent of those who were first-year boaters on the reservoir thought that crowding was a problem, 47 percent of those who had boated 2 years or more felt it was a problem ($P < .001$). Of those who had boated on the reservoir in the year before the study, perception of crowding increased as number of days' boating increased: 10 days or less, 38 percent; 10 to 29 days, 47 percent; 30 days or more, 55 percent ($P < .001$).

The type of water activity he engaged in did not correlate with the boater's perception of crowding, but the number of different activities did. Twice as many boaters who engaged in three or more water activities felt crowding was a problem as compared to those who engaged in fewer activities ($P < .001$).

Boaters' perception of crowding appears to be related to past boating experience and activity patterns. Where few types of water activities are available, the manager can expect fewer complaints about water areas that receive a high proportion of nonlocal and first-time boaters.

Water pollution. — Water pollution was seen as a problem by 3 out of 10 boaters. Significant differences were observed in boaters' perception of water pollution between local and nonlocal boaters, among boaters with different amounts of boating experience on the reservoir, and among boaters with different educational backgrounds.

While 45 percent of local boaters thought pollution was a problem, only 19 percent of nonlocals felt it a problem ($P < .01$). More of the boaters who had boated on the reservoir for 2 or more years felt that pollution was a problem (41 percent) than first-time or first-year boaters ($P < .01$). Similarly, 38 percent of boaters who had boated during the previous year felt that pollution was a problem, as compared to 17 percent of those who did not boat during the previous year ($P < .05$).

The number of water activities engaged in was also correlated with perception of pollution. While 4 out of 10 boaters who engaged in 3 or more water activities felt that pollution was a problem, 3 out of 10 who engaged in fewer activities felt it a problem ($P < .10$). Finally, almost twice as many boaters with high school or less education felt pollution was a problem as boaters with some college training ($P < .05$).

Lack of rule enforcement. — One out of four boaters felt that lack of rule enforcement was a problem. Differences in percep-

tion of enforcement were closely related to differences in perception of other management problems. Past boating experience, activity, and group size were correlated with perception of rule enforcement.

While 3 out of 10 local boaters perceived lack of rule enforcement as a problem, only 2 out of 10 nonlocal users felt the same ($P < .10$). Over half of the nonpower boaters, twice as many as power boaters, felt that lack of rule enforcement was a problem ($P < .10$). The proportion of boaters who felt that lack of enforcement was a problem increased as boating experience increased—17 percent of first-year boaters, 29 percent of 2- to 5-year boaters, and 33 percent of 6- or more year boaters ($P < .05$). Respondents from boating groups of two or less, who tended to be fishermen, more often found lack of rule enforcement a problem than boaters from larger groups ($P < .10$).

Conflicting use.—One out of four boaters thought that conflicts between water activities were a problem. The proportion decreased as motor size and investment in boating equipment increased ($P < .001$). More than twice as many boaters who used motors of 25 horsepower or less (53 percent) felt conflicting use to be a problem as did boaters with larger motors. Forty-four percent of nonpower boaters felt it to be a problem. Although half of the boaters with $600 or less invested in equipment felt conflicting use to be a problem, only 14 percent of those with $3,000 or more invested felt the same. Whether a boater was a fisherman or not influenced his perception of conflicting use. While only 2 in 10 nonfishermen felt it was a problem, nearly 5 in 10 fishermen thought so ($P < .05$).

Where motors of different sizes are permitted, and where fishing is allowed in addition to other activities, the manager can expect conflicting attitudes toward water use. The boater with a large motor appears to be unaffected by boaters with small motors. The opposite is not true — fishermen are influenced negatively by other activities but they have little influence on other activities.

Reaction to Management Proposals

Campers

As recreation pressures increase, controls are necessary to maximize the amount and quality of recreation while preserving the resource *(Lime and Stankey 1971)*. Yet managers have often been reluctant to control use because of anticipated adverse reaction.

The reactions of campers to seven control proposals were investigated: limiting the number of people allowed to use a campground; charging increased entrance fees; limiting all camping to designated areas; strengthening enforcement of rules and regulations; increasing patrols by uniformed law enforcement officers; developing more facilities; and restricting further campground development along the water.

Direct controls on use. — Campers were asked whether they felt capacities should be established for developed campgrounds and use kept at or below these levels.

Half the campers felt that capacities should be established and enforced. When asked why they felt this way, nearly 7 in 10 said that such control would eliminate overcrowding. Reasons for opposing controls were equally divided among: "It would be unfair to people traveling long distances," "all people have the right to use a public recreation area," "there simply is no need to control use because no problem exists," and "maximum consideration should be given to provide for as many users as possible without controls."

Childhood residence and length of trip were significantly ($P < .05$) correlated with attitude toward use controls. Twenty-two percent of campers who grew up in farm or rural areas felt that use should not be controlled, as compared to 67 percent of campers from urban backgrounds. Campers who stayed 8 days or more showed less support for limits on use than those who stayed shorter periods—66 and 40 percent, respectively.

Entrance fees. — Campers were asked whether camping fees should be increased above the existing $2.00. They were told

that a fee increase would more fully cover campground maintenance and development costs. Campers were also asked what fee level seemed most reasonable. Thirty-seven percent felt that, if necessary, fees should be increased; 56 percent felt that fees should not be increased; and 7 percent expressed no opinion.

Most campers felt that higher fees were justified only if additional facilities and services, like electricity and water connections, were made available at campsites. Campers who opposed higher fees argued that people should be able to use public recreation facilities at a minimal charge or free.

Practically all campers agreed that a fee should be charged. One in 10 said the fee should be less than the current $2.00, 6 in 10 said a $2.00 fee was about right, and the remainder felt a fee from $2.01 to $3.00 was reasonable. Few campers felt a fee higher than $3.00 should be charged, even with substantial facility improvements. The overall average of fees campers considered "most reasonable" was $2.16 (fig. 3).

Campers from urban backgrounds were twice as likely to support an increase in fees as those from farm and rural backgrounds ($P < .05$). The total number of days they camped during their current trip was also related to campers' opinions of increased fees, with half of the campers who stayed 7 days or less approving an increased fee, as compared to 20 percent of those who stayed 8 days or more ($P < .05$).

Controlled camping. — Respondents were asked whether people should be free to camp anywhere or allowed to camp only in designated areas. Sixty-five percent felt that

Figure 3.—Central entrance points to designated campgrounds are used to control use and collect fees. Although campers feel existing fee levels are justified, most are not willing to pay more even if additional facilities are provided.

Figure 4.—On weekends and holidays, undesignated camping areas spring up all around the reservoir area wherever access is available.

camping should be restricted to specified areas. Although most agreed with a restrictive policy, respondents felt that the policy would not work unless sufficient overflow camping areas were provided (fig. 4).

Campers who opposed use controls argued that the policy would restrict the freedom of those who sought a camping experience in a semi-primitive environment. Their general opinion was that "uncontrolled camping" was not a problem.

Over half of the respondents who lived in small cities and towns supported a controlled camping policy as compared to 77 percent of those from large cities ($P < .05$). The more people camped in the reservoir area, the less likely they were to support controls. Half of those who camped for 8 days or more felt that camping should be restricted as compared to 75 percent of those who stayed 7 days or less ($P < .05$). Similarly, campers who had camped on the Allegheny for more years showed less support for controls than first-year campers ($P < .05$).

Enforcement of rules and regulations.—All campers agreed that some form of reprimand or punishment should be given for violation of rules and regulations. When asked why they felt this way, three out of five said reprimand or punishment is necessary to prevent destruction of resources and facilities. One out of five felt that punishment was necessary to guarantee the freedom of other campers. The remainder said that the threat of punishment was the only way to enforce rules and regulations effectively.

Campers were asked what kind of punishment they would recommend for destroying vegetation or facilities. They suggested four types of punishment: fines of $25.00 to

$100.00 (69 percent); restricting the culprit's use of the facilities (12 percent); compulsory work to restore the area (15 percent); and a verbal reprimand for first-time offenders (14 percent).

Law enforcement.—Eighty percent of the campers felt that regular patrols by uniformed law enforcement officers were desirable. Four reasons were given: to protect campers and their equipment (24 percent); to enforce rules and regulations (20 percent); to protect the resources and facilities (18 percent); and to give information and assistance (15 percent). Campers who opposed regular patrols felt that either they were not needed or that regular patrols would restrict individual freedom.

As might be expected, only 70 percent of the campers with less than $1,500 invested in their equipment felt the need for increased patrols, as compared to 90 percent of those with greater investments ($P < .05$).

Increased facilities. — About half of the respondents felt that additional facilties were needed. Respondents with different backgrounds, those from different sizes of camping groups, those with different kinds of camping equipment, and those with different amounts of camping experience showed different response patterns.

Respondents from urban backgrounds were twice as likely to express a need for increased facilities as those from rural backgrounds ($P < .05$). Similarly, twice as many campers from groups of three or more adults wanted more facilities as did campers from smaller groups ($P < .05$).

As would be expected, style of camping influenced campers' attitudes toward facility development. Tenters were evenly divided on the need for more facilities. Only 4 out of 10 who used tent trailers felt the need for increased facilities as compared to 6 out of 10 mobile home users ($P < .10$).

Campers who stayed relatively short periods and those who stayed relatively long periods wanted added facilities. Of those campers who stayed 3 nights or less, 64 percent wanted increased facilities as did 56 percent who stayed 8 nights or more. But only 40 percent of those who stayed from 4 to 7 nights wanted additional facilities ($P < .10$). Campers who had been coming to the Allegheny for at least 2 years felt that additional facilities were needed twice as often as did those who were camping there for the first year ($P < .05$).

Restrict shoreline development.—Six out of ten respondents disapproved of further campground development along the reservoir shoreline. But they differed according to the distance they traveled, their camping style, and their past camping experience. Campers who had traveled less than 100 miles to reach the reservoir showed almost twice as much support for restricting development as those who had traveled longer distances ($P < .05$). Although only 4 out of 10 tent campers were for restricting campground development, 7 out of 10 mobile home campers supported it ($P < .05$). Campers who had camped on the reservoir for 2 years or more were more likely to support restricted development than those who were camping there for the first year ($P < .05$).

Boaters

As the demand for water-based recreation grows, managers are increasingly concerned with maximizing use without adversely influencing either water quality or boater safety. Boaters were asked for their views on five water-management policies: zoning the reservoir for recreational uses; charging boat-launching fees; increasing punishment for violators of water regulations; increasing water patrols; and increasing facilities.

Zoning.—Four out of 10 boaters felt that recreational uses of the reservoir should be separated by zones. Reasons given were that each water activity could proceed unhindered and that boating would be safer. Major reasons for opposition to zoning were that zoning simply was not needed and that it would unduly restrict individual freedom.

Boaters' attitudes toward zoning differed with characteristics of the boating group. For example, only 37 percent of the respondents from groups with children supported zoning, but 51 percent from groups without children supported it ($P < .05$). Boaters under 50 years of age were almost twice as

likely to support zoning as those over 50 ($P < .01$).

Part of the difference in boaters' attitudes toward zoning depended on their activities. Although 73 percent of the respondents who fished favored zoning, only 39 percent of those who did not fish felt zoning was needed ($P < .05$). The more active boaters were less likely to support zoning. Half of the boaters who engaged in only one water activity favored zoning, while 3 out of 10 who participated in two or more activities supported it ($P < .05$). Fifty-five percent of the respondents who did their boating within 1 mile of their launch site supported zoning, as compared to 38 percent of those who visited more remote parts of the reservoir ($P < .05$). Boaters who also camped were twice as likely to support zoning as day-use boaters ($P < .05$).

Launching fees.—Boaters were evenly divided on their attitude toward boat-launching fees. Of those who opposed lanching fees, half felt that the public should not be charged for using public boat launchings. Another ten percent said that launching fees would discriminate against the economically disadvantaged. Others felt that launching fees should be included in camping fees and that separate launching fees would be appropriate only for day-users.

Boaters who were for charging a fee said it would be justified only if existing launching facilities were improved. The daily fee suggested by 9 out of 10 boaters who supported launching fees averaged $1.25. Some boaters felt an annual fee would be more equitable.

The only difference among groups in their attitude toward launching fees was that twice as many respondents from groups without children were willing to pay a fee as those from groups with children ($P < .05$). A closely correlated variable, total group size, showed a similar relationship.

Punishment for violations. — Nearly all boaters favored some form of punishment for violation of water regulations. Half of them felt that adequate punishment would prevent damage to the reservoir and improve water safety. One-quarter felt punishments were necessary to protect individual freedom.

When boaters were asked what kind of action should be taken against first-time violators, responses were equally divided among a verbal reprimand, suspension of boating privileges, a mandatory water safety education program, and a fine of from $1 to $100.

Regular water patrols. — Boaters were asked whether they felt regular water patrols were needed. Eighty-eight percent said they were. Half of those who favored patrols felt they were needed to enforce rules and regulations. Another one-quarter said regular patrols would improve water safety, and 10 percent said patrols would provide assistance when needed. No characteristics of the respondent or group were found to be related to the boater's attitude toward regular water patrols.

Increase facilities. — Overall, 6 out of 10 boater-respondents wanted more boating facilities, such as docks, launching sites, and marinas. But this attitude was not shared evenly by all segments of the boating population.

Although 78 percent of the boaters under 40 years of age expressed a desire for more facilities, only 40 percent of those 40 or over felt the same ($P < .05$). Local boaters — those who had traveled 25 miles or less — were twice as likely to express a desire for increased facilities as boaters who had travel 200 miles or more ($P < .05$).

The length of time boaters were on the reservoir the day they were interviewed was also related to their attitude toward facility needs. Among day-use boaters, 7 out of 10 of those who boated 4 hours or less wanted increased facilities, as compared to 4 out of 10 of those who boated 5 hours or more ($P < .01$). Fifty-nine percent of boaters who camped overnight at campgrounds accessible by boat desired increased facilities.

The type of boating equipment and the amount invested in it were related to the boater's attitude toward the need for more facilities. Among power boaters, those who used motors of 30 horsepower or more were three times as likely to express a desire for increased facilities as those who used small-

er motors ($P < .01$). The proportigon of boaters who wanted more facilities also increased as the amount invested in equipment increased—17 percent, 53 percent, and 64 percent, respectively, for boaters with equipment investments of less than $600, $600 to $1,500, and more than $1,500 ($P < .01$).

MANAGEMENT IMPLICATIONS

The results of this study have direct application to planning and management of the Allegheny Reservoir area. But the information should be useful in other places where management decisions need to be made and where knowledge of the recreation user, his attitudes and opinions, is incomplete. Our data on the characteristics of recreation users can be compared to the characteristics of users in other areas to estimate the applicability of our results.

Differences Between Users

Few differences were found between campers and boaters in age, income, or occupation. They did differ, however, in past visitation, length of stay, distance traveled, education, investment in equipment, group composition, and recreation activities.

Recognition of similarities and differences between groups of users provides insight into their needs. For example, both campers and boaters averaged more than 5 years of previous experience, but campers were more likely to be first-year visitors. Knowing this makes it possible to direct orientation programs toward those most in need of them.

Information on how long people stay is also valuable in making management decisions. In this study, over half of all campers stayed 6 days or more. Half of the boaters were day-users. Most boaters who camped stayed 5 days or less. Although most boating takes place on weekends, camping is more evenly distributed through the week. This information can help to establish more effective administrative staffing and maintenance schedules, and to develop policies designed to reduce peak use pressures.

A relationship was found between distance traveled and length of stay—the farther people traveled, the longer they stayed. This relationship has direct application to facility and administrative planning. Data on the origins of visitors can be used to make consumption forecasts that reflect changes in population distribution and travel systems. Visitor-origin data can also be used to direct informtion and education more selectively through press releases, radio, and television.

The modern camper is often thought of as using highly mobile, self-contained, sophisticated camping equipment. Our study results indicate that this type of camper has not entirely replaced the conventional tent camper. On the other hand, 95 percent of the boaters used power boats, and most used motors of more than 40 horsepower. These different visitors require different kinds of facilities. As this study shows, users are not unanimous in their assessment of facility needs.

Both differences and similarities were found between campers and boaters. These can be important considerations in planning and designing facilities.

User Satisfaction

Although managers commonly feel that recreation resources are overused, neither group in this study felt overuse to be a serious problem. They tended to see "overuse" as crowding that influenced their own recreation experiences. Few related overuse to impact on natural resources. At least in the mind of the user, the carrying capacity of a recreation resource is determined more by the effect of crowding on user satisfaction than by site deterioration (fig. 5).

When asked whether capacities should be established and use limited to them, half of the campers felt such a policy would be desirable. Planners and managers should recognize that the level of recreation use can directly influence the quality of the experience. The exact influence that a controlled-use policy would have on user satisfaction is not presently understood.

Our findings support the notion that the carrying capacity of a recreation area is not

Figure 5.—The Allegheny Reservoir near Cornplanter bridge. As recreation use increases from spring to summer, crowding results in physical and biological site degeneration. Recreation users associate crowding with a reduction in the quality of their recreation experience.

determined solely by the ability of the area to sustain heavy use, but also by the ability of the management system to sustain a particular level of user enjoyment *(Chubb and Ashton 1969)*.

When asked to criticize management, both campers and boaters emphasized the facilities and services provided. As basic needs are provided for, "needs" seem to become more sophisticated. For example, once an area is designated for camping, facility needs expand from pit to flush toilets, from a cold water faucet to hot showers, and from no services to concession facilities. Boaters' needs expand from launching sites to dock space; from no service facilities to intermediate facilities, such as bait shops, boat rentals, and tour boat rides, and, eventually, to the sophisticated services offered by a full-service marina. Planners and managers must understand the potential consequences of this process—haphazard facility development, added maintenance costs, and disjointed planning. Recreation managers and planners should recognize the commitment they make for the future at each planning step in the recreation development process.

Recreation users are not unanimous in their attitude toward management. Our study indicates that users who are more familiar with a recreation area—because they either come more often, stay longer, come from nearby communities, or are more active — are less satisfied with management than those who are less familiar with the area. Therefore, the manager who serves a population of users who are quite familiar with his area can expect a high proportion of relatively dissatisfied users.

Satisfaction with management also depends on user-group characteristics. For example, this study shows that larger camping groups, particularly those with children, are less satisfied than smaller groups—they require more from management. For boaters, satisfaction with management decreased as investment in equipment and income increased: higher-income users with more expensive equipment expect more from management.

Perception of Management Problems

Recreation users and managers perceived and reacted to management problems differently. While managers thought littering, unsanitary conditions, and destruction of vegetation were serious problems on the Allegheny, campers did not feel that these were problems. But uncontrolled camping was seen as a problem by both managers and campers.

The manager and recreation user look at "management problems" from different perspectives. While the manager is concerned both with meeting present demands and preserving the resource, the user is concerned with short-term consumption of the resource. These two perspectives must be carefully balanced to make equitable decisions about resource policy.

Our study indicates that different users perceive management problems differently. For campers, familiarity with the camping area increases perception of management problems — particularly unsanitary conditions and destruction of vegetation. In camping areas with a large proportion of repeat visitors, the manager can expect more critical users. Uncontrolled camping, as defined in this study, is viewed as a problem by campers who live near the reservoir. They are also likely to be repeat visitors and more familiar with the area. Managers of campgrounds that attract a high percentage of large groups are likely to have difficulty restricting camping to designated areas because, as this study shows, large groups do not perceive uncontrolled camping as a problem.

Boaters differ in their perception of management problems as campers do. Boaters who were familiar with the reservoir, either because they lived nearby, boated more often, or participated in more water activities, perceived more management problems. Boaters who used small motors or none, and those who fished, felt strongly that conflicting uses of the reservoir and lack of adequate rule enforcement were management problems. Nonfishermen and boaters who used large motors did not share these feelings.

Reaction to Management Proposals

Control of recreation use, either through space allocation or direct controls on numbers of users, is seen by both the manager and user as a necessary part of future resource planning. But support for it is not unanimous among all segments of the recreating public.

For campers interviewed in this study, childhood residence — where the respondent lived before the age of 16—was significantly correlated with attitude toward management proposals. Those with rural backgrounds showed less support for controls on recreation use, changes in fees, and added facility development, than campers with urban backgrounds. As urbanization of the population continues, the manager can expect that more campers will support these policies.

A manager who attempts to establish use controls can expect resistance from local users and from those who camp for extended periods. Campers who had camped on the Allegheny during more than 1 year were more in favor of increased facility development and less in favor of restricting further campground development along the shore than were other campers. Campers who camped for longer periods showed less support for establishing capacity use standards, restricting use to designated camping areas, and changing fees.

Camping style was correlated with campers' attitudes toward management. Tent campers were less in favor of restricting where camping is permitted and restricting further campground development along the reservoir than were other campers. Tent campers, who were usually in groups of four or fewer, also did not feel the need for increased facility development as did other campers, who were usually in larger groups.

Different segments of the boating population also react differently to management. In this study, fishermen endorsed zoning, but all other boaters, particularly those with children and those who participated in a large number of water activities, showed little support for zoning. Where many recreational activities are permitted on the same body of water, the manager can expect controversy over the need for zoning.

Boaters from groups with children and those from larger groups were more likely to be opposed to launching fees than other boaters. Boaters who used the reservoir more—either because they lived nearby, stayed on the water longer, or had larger, more expensive boats—showed more support for augmenting boating facilities than other boaters did.

CONCLUSIONS

Any change in recreation management is likely to have different impacts on different recreation users. Resistance will be encountered unless the change affects all segments of the recreating population favorably. Recreation users are likely to support a policy "as long as it's fair." Thus the major issue in changing recreation management policy is defining what is "fair" and what is "unfair" to which segments of the recreating public. The following points, condensed from this study, may help to resolve this issue.

- Recreation users see an infinite resource, if not in space, certainly in time. They are concerned with their own experience which has fixed time and space requirements. This perspective needs to be reconciled with management planning.
- Changes in rules and regulations and their enforcement affect the recreation public equally. Most other changes are likely to affect local users differently from nonlocal users.
- Policy changes will have different impacts on users depending on how active the users are, either in terms of the number of activities they participate in or the distance they cover.
- Desires and "needs" change with the level of recreation facility development; consequently the impact of management decisions depends on the existing degree of facility development.
- Recreation users agree with decisions that are equitable and do not excessively restrict individual freedom. But the user must be given the rationale for a particular management decision.

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APPENDIX A

Characteristics of Respondents

Table 1.—Distribution of respondents by income class, compared with national population

Annual family income (dollars)	Campers (N=157)	Boaters (N=281)	Census 1970
	— — — *Percent* — — —		
Less than $3,000	3	0	9
$ 3,000 to $ 8,000	18	16	28
$ 8,001 to $12,000	48	43	31
$12,001 to $20,000	26	30	21
More than $20,000	5	11	11

Table 2.—Camping equipment

Equipment	Campers (N=157)
	Percent
Tent	36
Tent trailer	26
Trailer	24
Pickup camper	10
Mobile home	4

Table 3.—Motor size

Horsepower	Boaters (N=267)[a]
	Percent
10 or less	4
11 - 25	6
26 - 40	20
41 - 60	18
61 - 80	22
81 - 100	10
Over 100	20

[a] Excludes 5 percent of boats that were non-powered.

Table 4.—Distance traveled from home to the reservoir

Distance traveled (miles)	Campers (N=157)	Boaters (N=281)
	Percent	*Percent*
0 - 25	12	36
26 - 50	4	7
51 - 100	17	23
101 - 150	34	21
151 - 200	15	11
201+	18	3

Table 5.—Length of stay

Length of stay (nights)	Campers (N=157)	Boaters (N=281)
	Percent	*Percent*
0[a]	0	46
1 - 5	9	19
3 - 5	34	20
6 - 7	23	8
8 - 11	20	5
12 - 14	14	2

[a] Did not stay overnight.

APPENDIX B
Camper Questionnaire

RECREATION MANAGEMENT STUDY - ALLEGHENY NATIONAL FOREST

CAMPER INTERVIEW SCHEDULE

Interviewer Instruction: Interview the head of the camping group. If more than two groups are present at the site, select the respondent by tossing a coin. Record information below and introduce yourself as follows:

"Good morning (afternoon), sir. I am a graduate student at the New York State College of Environmental Science and Forestry at Syracuse, New York. I am conducting a study of camper opinions concerning recreation management problems on the Allegheny National Forest. The study will provide managers with the information they need to improve the recreation services that are provided for people like yourself. You have been randomly selected from among the campers here today to express your opinions concerning management policies. Can you spare 15 minutes for a brief interview? Your answers will be held in strict confidence and will be used only to represent the view of a typical camper."

Fill in this information:

Sex of Respondent: M ( ) F ( )

Race of Respondent: Black_____
White_____
Other_____

Type of Equipment: Tent _____
Tent Trailer _____
Trailer _____
Pick-up Camper_____
Mobile Camper _____

Use intensity estimate:

Campground: Full ( )
3/4 Full ( )
1/2 Full ( )
1/4 Full ( )
Or Less ( )

Interviewer:_____

Weather:_____

Date:_____

Campground Name:_____

Site Number:_____

Sampling Ratio:_____

Q 1. How many people are in your camping group today?_____

Person (relationship to respondent)	Age
(respondent)	

Q 2. How many years have you been camping?_____

Q 3. How many years have you been coming to the Allegheny National Forest for recreation?_____

Q 4. How many years have you camped on the Allegheny National Forest?_____

Q 5. How many days did you spend camping (anywhere) last year?_____

Q 6. a. How many days did you spend camping on the Allegheny last year?_____

b. How much of this was done on the Reservoir?_____(days)

Q 7. What are your reasons for visiting the Allegheny National Forest this trip?

_____

Q 8. How many nights have you already spent camping here?_____

How many more nights do you plan to stay?_____

Q 9. On this camping trip, could you tell me the places you have visited on the Allegheny National Forest and what activities you have participated in?

Places	Activities

Q 10. Are you a member of any conservation group, outdoor club, or other organized recreation group? (List):

Memberships	Years in Membership

Interviewer Read: "As a typical camper on the Allegheny National Forest, we are interested in how you feel about management of the campground around the Reservoir."

Q 11. a. Is there anything about these camping areas that you would like to see changed?_____

_____

_____

b. What do you feel recreation managers should do, if anything, about these problems?_____

_____

_____

Q 12. From your experience with these camping areas, would you say that any of the following are problems? (Ask in order and check response):

	Littering	Unsanitary Conditions	Vegetative Destruction	Uncontrolled Camping (define)
Yes	_____	_____	_____	_____
No	_____	_____	_____	_____
Undecided	_____	_____	_____	_____

Q 13. a. What is your impression of the overall use intensity of camping areas around the Reservoir? (Check):

_____ Greatly overused
_____ Slightly overused
_____ Neither overused nor underused
_____ Slightly underused
_____ Greatly underused
_____ No opinion

b. Would you say that this area is being overused today?

( ) Yes ( ) No ( ) No Opinion

Q 14. Will you tell me what the phrase "overuse" means to you?

_____

_____

Interviewer Read: In order to eliminate problems of overuse and improve the recreation experience, recreation managers have considered several management proposals. We would be interested in your reactions to these proposals.

Q 15. a. Some recreation managers feel that anyone should be able to camp anywhere. Other managers suggest that the number of people per day be limited to reduce problems of littering, sanitation, and vegetative destruction that result from heavy use. How do you feel?

( ) Agree with unlimited use
( ) Neutral
( ) Agree with limited use

b. Why do you feel this way?

_____

_____

a/

Q 16. a. Some recreation managers feel that camping should be made available at a minimum fee. Others suggest that a higher fee, more in line with those charged at similar commercial campgrounds, would insure that more money could be available for your proper maintenance and improvement of the area. How do you feel?

( ) Approve minimum fee

( ) Neutral

( ) Approve of higher entrance fee

b. Why do you feel this way?_____

_____

c. What daily fee seems most reasonable to you?_____

Q 17. a. Some recreation managers suggest that campers should be allowed to camp anywhere on the Forest. This would provide all recreationists the opportunity to camp where they want to camp. Other managers feel that camping should only be allowed in designated areas to control littering, unsanitary conditions, and vegetative destruction. How do you feel?

( ) Feel that camping should be allowed anywhere on the Forest

( ) Neutral

( ) Feel that camping should be only in designated areas

b. Why do you feel this way? (Key question--probe).____

_____

Q 18. a. Some recreationists feel that the enforcement of rules and regulations tends to restrict their sense of freedom in this outdoor environment. Others feel that a reprimand should be given to anyone found defacing recreation facilities or destroying vegetation. Still others feel that offenses such as these warrant some form of punishment. How do you feel?

( ) Want sense of freedom?

( ) Approve of Reprimand?

( ) Approve of punishment?

b. Why do you feel this way?_____

_____

c. (If respondent approves of reprimand or punishment). If apprehended, what sort of reprimand or punishment should be ordered?_____

_____

---

a/ The question elements for questions 16 through 21 were reversed on half of the questionnaires to reduce the possibility of response bias due to question structure.

Q 19. a. Some campers feel that uniformed law enforcement officers regularly patrolling the reservoir area would tend to detract from their recreational experience, while others feel that a patrol would be a good idea. How do you feel?

( ) Do not want a regular patrol

( ) Neutral

( ) Agree with value of a regular patrol

b. Why do you feel this way?_____

_____

Q 20. a. Some visitors feel that the character of the Reservoir area would be ruined with the development of additional facilities. Others feel that the area should be developed with additional facilities. How do you feel?

( ) Additional facilities not needed

( ) Neutral

( ) Additional facilities are needed

b. Why do you feel this way?_____

_____

c. (If respondent wants additional facilities). What additional facilities would you suggest?_____

_____

Q 21. a. Some managers have suggested expansion of shoreline camping facilities. But others feel that the interests of more people would be served, in the long run, if new camping facilities were constructed a mile or more away from the shoreline. How do you feel about this?

( ) Agree with expansion of shoreline camping facilities

( ) Neutral

( ) Agree with restricting additional shoreline camping facilities

b. Why do you feel this way?_____

_____

Q 22. a. How do you feel about the number of recreationists in this vicinity today? Does it tend to reduce the area's recreational appeal?

( ) Yes

( ) Neutral

( ) No

b. Why do you feel this way?_____

_____

Interviewer Instruction: (Hand respondent cards and enter appropriate responses:) Using this card and beginning with Question 23, could you please tell me:

Q 23. The code value of the age class in which you fall?_____

Q 24. The code value of your present gross family income?_____

Q 25. How many years of education you have completed--excluding trade schools and military schools?_____

Q 26. The code value of the amount of money you have invested in your camping equipment? $_____

Q 27. On the average, what type of community would you say you resided in before the age of 16?

_____Farm
_____Rural, non-farm
_____City - 10,000 - 99,999
_____Major cities 100,000+
_____Don't know
_____Not ascertained

Q 28. Where do you now live?_____(City and State)

Q 29. Are you married? _____Yes _____No

Q 30. What is your present occupation?_____

_____Housewife (Go to question 31)

_____ Unemployed

_____Retired

Q 31. What is your husband's occupation?_____

Interviewer Instruction:

( ) Check if respondent wants a copy of the study results.

THANK RESPONDENT AND TERMINATE THE INTERVIEW.

APPENDIX C
Boater Questionnaire

ALLEGHENY NATIONAL FOREST

Interviewer Instruction:

Interview the person in the returning boat who is driving the boat when it is docking. For non-powered boats, interview the head of the group, when it is docking. Interview boaters 18 years of age or older. Introduce yourself as follows:

"Good morning (afternoon) sir: I am a graduate student at the New York State College of Forestry at Syracuse, New York. I am conducting a study of boater opinions concerning recreation management problems on the Allegheny Reservoir. The study will provide managers with the information they need to improve the recreation service for people like yourself. You have been randomly selected from among the returning boaters to express your opinions concerning reservoir management policies. I know that you are in a hurry now and could not spend much time talking to me, so I have prepared a brief mail-back questionnaire for you to fill out at your leisure. A postage paid return envelope is provided for your convenience."

Interviewer fill in this information:

Questionnaire Identification Number:_____

Sex of Respondent: ☐ M ☐ F

Race of Respondent: ☐ White ☐ Black ☐ Other

Use Intensity Estimate:

Parking Lot: ☐ Full ☐ 3/4 Full ☐ 1/2 Full ☐ 1/4 Full or less

Interviewer:_____

Weather:_____

Water Condition:_____

Date:_____

Launch Site Name:_____

Sampling Ratio:_____

Name and Address:

_____

_____

_____

Number in Boat:_____

List:

Respondent	Sex	Estimated Age
_____	___	___
_____	___	___
_____	___	___
_____	___	___
_____	___	___

BOATING SURVEY QUESTIONNAIRE

Questionnaire Identif No._____

Q 1. What kind of boat do you own? Type: (Check):
Power_____ Non-Power_____ Length_____Horsepower_____

Q 2. How many years have you been boating (anywhere)?_____(years)

Q 3. How many years have you been boating on the Allegheny Reservoir?_____(years)

Q 4. How many days did you boat on the Allegheny Reservoir last year?_____(days)

Q 5. How long were you on the water the day you received the questionnaire?_____(hours)

Q 6. What water activities did you participate in the day you received this questionnaire and where on the Reservoir did you participate in these activities?

Activity	Area of Reservoir
_____	_____
_____	_____
_____	_____

Q 7. What places on the Allegheny National Forest did you visit the day you received this questionnaire and what activities, other than boating, did you participate in?

Places	Activity
_____	_____
_____	_____
_____	_____

Q 8. For the trip when you received this questionnaire, how many days did you spend on the Allegheny?_____(days)

Q 9. Please list any conservation groups, outdoor clubs, or any other organized recreation groups in which you have a membership.

Group Memberships

_____

_____

_____

"As a typical boater on the Allegheny Reservoir, we are interested in how you feel about management of the Reservoir".

Q 10. a. Is there anything about the management of the Reservoir or facilities available that you would like to see changed?_____

_____

b. What, if anything, do you feel recreation managers should do to alleviate these problems?_____

_____

Q 11. From your boating experience on the Reservoir, would you say that any of the following four conditions exist? (Check how you feel along the scale provided).

Problem or Condition	Check how you feel: Not a Problem	Neutral	Yes, a Problem
1. Water pollution	☐	☐	☐
2. Overcrowding	☐	☐	☐
3. Conflicting uses (boating versus fishing, etc.)	☐	☐	☐
4. Lack of enforcing rules and regulations	☐	☐	☐

Q 12. What is your impression of the use-intensity of the Reservoir? (Check):

☐ Greatly overused
☐ Slightly overused
☐ Neither overused or underused
☐ Slightly underused
☐ Greatly underused
☐ No opinion

"In order to improve your recreation experience, managers have considered several management proposals. We would be interested in your reactions to these proposals."

Q 13.[a/] a. Some recreation managers would like to see the Allegheny Reservoir completely free of user zones, that is, areas designated for power boating, fishing, water skiing, etc. Others have suggested that user zones may reduce crowding and improve safety. How do you feel? (Check one):

☐ Disagree with zoning for users
☐ Neutral
☐ Agree with user zones

b. Why do you feel this way?_____

_____

Q 14. Some recreation managers feel that launching a boat on the Reservoir should be free. Others suggest that a fee, more in line with that charged at commercial facilities, would insure that more money could be available for proper maintenance and improvement of facilities. How do you feel? (Check one):

☐ Approve of free launching
☐ Neutral
☐ Approve of a launching fee

[a/] The question elements for questions 13 through 17 were reversed on half of the questionnaires to reduce the possibility of response bias due to question structure.

Q 15. a. Some boaters feel that the enforcement of rules and regulations tend to restrict their sense of freedom while on the water. Others feel that a reprimand should be given to anyone found causing unsanitary conditions or wilfully endangering other users of the Reservoir. Still others feel that offenses such as these warrant some form of punishment. How do you feel?

☐ Disapprove of either reprimand or punishment

☐ Approve of reprimand

☐ Approve of punishment

b. Why do you feel this way?_____

_____

c. If you suggest either a reprimand or a punishment, what should be ordered if you were apprehended?_____

_____

Q 16. a. Some boaters feel that uniformed law enforcement officers regularly patrolling the Reservoir would tend to detract from their recreational experience, while others feel that a patrol would be a good idea. How do you feel?

☐ Do not want a regular patrol

☐ Neutral

☐ Agree with the value of a regular patrol

b. Why do you feel this way?_____

_____

Q 17. a. Some visitors feel that the natural character of the Reservoir might be ruined with the development of additional facilities such as marinas and more day use areas. Others feel that the Reservoir needs more of this type of development. How do you feel?

☐ Additional facilities are not needed.

☐ Neutral

☐ Additional facilities are needed

b. Why do you feel this way_____

_____

Q 18. Do you feel that the number of boaters on the Reservoir the day you received this questionnaire tended to reduce the Reservoir's recreational appeal?

☐ Yes

☐ No

☐ No Opinion

"We are interested in some personal information about the boaters who use the Allegheny Reservoir. The information you provide will be held in strict confidence, and in no way will ever be identified with your response since your name does not appear on this questionnaire."

Q 19. Please check the gross family income category in which you fall?

- ☐ Less than $5,000
- ☐ $3,000 to $8,000
- ☐ $8,001 to $12,000
- ☐ $12,001 to $20,000
- ☐ Over $20,000

Q 20. How many years of education have you completed excluding trade schools and military schools?_____(years)

Q 21. Please check the category corresponding to the amount you have invested in your boating equipment.

- ☐ Less than $300
- ☐ $300 to $600
- ☐ $600 to $1,500
- ☐ $1,500 to $3,000
- ☐ $3,000 to $6,000
- ☐ Over $6,000
- ☐ Don't own equipment

Q 22. What size community did you live in before the age of 16?

- ☐ Farm
- ☐ Rural non-farm
- ☐ City of less than 10,000
- ☐ City - 10,000 to 99,999
- ☐ City - 100,000 or more

Q 23. Where do you live now? City_____State_____

Q 24. Are you married? ☐ Yes ☐ No

Q 25. What is your present occupation? (Please be specific)_____

_____

☐ Please check box if you would like to receive a copy of the study results.

THANK YOU VERY MUCH FOR YOUR TIME AND ASSISTANCE

Moeller, George H., Rodney G. Larson, Douglas A. Morrison.
1974. **Opinions of campers and boaters at the Allegheny reservoir.**
NE. Forest Exp. Sta., Upper Darby, Pa.
26 p., illus. (USDA Forest Serv. Res. Pap. NE-307)

Interviews with 157 campers and 281 boaters near the Allegheny reservoir on the Allegheny National Forest revealed that their perceptions of management problems differed from those of managers. Different users had different attitudes toward recreation use controls, fee policies, recreation zoning, law enforcement, and facility development needs. This diversity indicates that changes in recreation management policy will not affect all recreation users equally; their impact will depend on how active the users are, the number of activities they participate in, and how familiar they are with the area.

907.2 : 922.1 (774)

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THE IMPACT OF **DEER BROWSING** ON ALLEGHENY HARDWOOD REGENERATION

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1974

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6816 MARKET STREET, UPPER DARBY, PA. 19082
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DAVID A. MARQUIS received his bachelor of science degree in forestry from The Pennsylvania State University in 1955, and his master's and doctoral degrees in forest ecology and silviculture from Yale University in 1963 and 1973 respectively. He joined the Northeastern Forest Experiment Station's silviculture research unit in New Hampshire in 1957, where he studied problems of regeneration and thinning in northern hardwoods. Between 1965 and 1970 he served on the timber and watershed management research staff at the Station's headquarters in Upper Darby, Pennsylvania. Since 1970, Dr. Marquis has been project leader of the silviculture research unit at Warren, Pennsylvania, where he heads a program of research on problems related to the regeneration and culture of high-value hardwoods on the northern Allegheny Plateau.

MANUSCRIPT RECEIVED FOR PUBLICATION 3 MARCH 1974

THE IMPACT OF **DEER BROWSING** ON ALLEGHENY HARDWOOD REGENERATION

by David A. Marquis

ABSTRACT

To evaluate the impact of deer browsing on Allegheny hardwood regeneration, surveys were made of vegetation inside and outside deer exclosures in 13 stands that had been clearcut 5 to 16 years earlier. The surveys showed that browsing by white-tailed deer has resulted in regeneration failures in 25 to 40 percent of the areas studied. Pin cherry and sugar maple were the species most severely reduced by browsing, while beech, birch, and striped maple sometimes increased in proportion to other species in areas subjected to deer.

The surveys also showed that successful regeneration was obtained in spite of deer browsing in over half of the clearcuts studied. Although not demonstrated here, other research has shown that the areas most likely to regenerate satisfactorily are those that contain abundant advance regeneration.

Data from this study, although limited, suggest that regeneration in 4- to 5-year-old clearcuts can be judged satisfactory if at least 60 percent of the 6-foot-radius plots examined are stocked with at least 2 desirable stems over 3 feet tall, or at least 100 desirable stems of any size.

SCIENTIFIC NAMES OF TREES MENTIONED IN THIS REPORT

Common name	*Scientific name*
Sugar maple	*Acer saccharum* Marsh
Red maple	*Acer rubrum* L.
Striped maple	*Acer pensylvanicum* L.
Yellow birch	*Betula alleghaniensis* Britton
Black birch	*Betula lenta* L.
Beech	*Fagus grandifolia* Ehrh.
White ash	*Fraxinus americana* L.
Yellow-poplar	*Liriodendron tulipifera* L.
Cucumber-tree	*Magnolia acuminata* L.
Aspen	*Populus grandidentata* Michx. or *Populus tremuloides* Michx.
Black cherry	*Prunus serotina* Ehrh.
Pin cherry	*Prunus pensylvanica* L.
Red oak	*Quercus rubra* L.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.

DEER BROWSING: A PROBLEM IN REGENERATION

HEAVILY FORESTED areas on the Allegheny Plateau in Pennsylvania and New York have supported an unusually large deer herd since the 1920s, and browsing of woody plants by these deer has affected development of vegetation for a long time *(Frontz 1930; Bramble and English 1948; Bennett 1957; Marquis 1973)*.

Understory vegetation is extremely sparse in most undisturbed Allegheny hardwood stands, and new seedlings that appear after forest cutting are often severely browsed. Many deer-exclosure studies on the Allegheny Plateau have demonstrated how deer delay, and sometimes entirely prevent, tree reproduction *(Grisez 1957; Shafer et al. 1961; Jordan 1967)*. In addition to interfering with the development of new trees, excessive browsing reduces further browse production, degrading deer range conditions, *(Stiteler and Shaw 1966)* which results in deer that are undersized and undernourished *(Jordan 1970)*.

Because there is much variation from place to place in the quantity and vigor of tree reproduction and the amount of deer browsing, it is difficult to judge the true impact of deer on tree regeneration. Most exclosure studies involve only one or two exclosures within a limited area. Such studies leave little basis on which to judge such important questions as how frequently and under what conditions deer actually prevent establishment of a new forest stand. To do this, data from a large number of exclosures over a wide range of sites and conditions are needed.

During the 1950s and 1960s, the Allegheny National Forest installed a series of deer exclosures in various stands. Most of these exclosures were located in recently cutover areas. In 1971, vegetation surveys were made on plots both inside and outside 13 of these exclosures (table 1). The results obtained from these surveys provide a measure of the impact of deer browsing on Allegheny hardwood regeneration in a four-county area in Northwestern Pennsylvania.

A cluster of 9 sample plots was located inside and another one outside each exclosure. The sample plots were arranged in 3 rows of 3 plots each, with 40 feet between plots. The cluster outside the exclosure was located in an area judged to have been as similar as possible to that inside the fence, on the basis

Table 1.—Exclosures surveyed

Stand No.	Sale area	Cutting complete	Fence built	Fence height	Area explosed
		Year	*Year*	*Feet*	*Acres*
	RECENT CLEARCUTS				
1	Railroad Run	1966	1966	6	0.5
2	North Branch Sugar Run	1965	1966	6	0.5
3	Hemlock Run	1966	1966	6	0.5
4	Wolf Run	1969	1969	8	8.0
5	Slide Run No. 2	1963	1963	8	0.5
6	Long Hollow	1965	1966	8	0.5
7	Lower Morrison	1965	1966	8	0.5
8	Fork Run	1966	1966	8	0.5
9	Farnsworth	1965	1966	8	0.5
10	Kinzua Trail	1965	1966	8	0.5
	OLDER CLEARCUTS				
13	Chappel Fork	1957	1957	8	1.0
14	Cherry Grove	1957	1957	8	1.2
20	Silver Creek	1956	1957	8	1.0

of topography, drainage, residual stand density, etc. The center plot of the outside cluster was located at least 100 feet from the fence to avoid atypical conditions that sometimes exist in the heavily traveled zone near the fence.

Sample plots were circular, with a radius of 6 feet. Trees were recorded by species and height classes, and the exact height of the tallest individual of each important species was recorded. Percentage of ground area covered by six major groups of herbaceous ground-cover plants was also recorded.

Several species groups are mentioned throughout the data tabulations that follow. *Preferred species* are those preferred for timber production; they include black cherry, sugar maple, red maple, yellow-popular, cucumber tree, and red oak. *Commercial species* are all those commercially valuable for timber; they include the preferred species plus beech, yellow birch, black birch, other oaks, hickory, and hemlock.

The students "t" test for paired observations was used to make statistical comparisons among fenced and unfenced plots.

The sample plot size used in this study (6-foot-radius, 1/385-acre) was selected because it corresponds approximately to the area occupied by a single tree of average diameter in a fully stocked Allegheny hardwood stand when that stand reaches merchantable size. Mean stand diameter of 8 inches is assumed to be the size at which the stand becomes merchantable. Fully stocked (A-level in stocking guides) Allegheny hardwood stands with mean diameter of 8 inches vary from about 330 to 485 trees per acre for stands with 0 to 80 percent intolerant species *(Roach 1974)*.

Such plots provide an especially appropriate size on which to judge reproduction stocking. If each 1/385-acre plot contains at least one stem that survives until the stand reaches merchantable size, the resulting stand will be fully stocked. It follows, therefore, that the proportion of these 1/385-acre plots satisfactorily stocked with reproduction should be related directly to the stocking level of the stand when it reaches merchantable size *(Leak 1969)*.

Since many stems present during the reproduction stage will die before the stand reaches merchantable size, it is apparent that more than one stem must be present to consider a reproduction plot satisfactorily stocked. Unfortunately, the definition of what constitutes a satisfactorily stocked plot at various ages has not yet been developed for Allegheny hardwoods. Therefore, in this report I have assumed a range of criteria—based on experience and observation in this type and data on normal mortality rates for northern hardwoods in New England *(Leak 1969)*—and have applied these assumed criteria to evaluate probable future stocking.

The assumed criteria include 10, 25, 50, 100, and 150 stems per plot. However, such criteria based on the number of stems of all sizes are not likely to be very reliable predictors of future stocking in Allegheny hardwoods, because deer browsing prevents many of these stems from growing beyond seedling size. More reliable criteria would be the numbers of stems that have already grown—or will soon grow—beyond the reach of deer. For this reason, criteria based on a minimum of 1 or 2 stems over 5 feet tall, and 2 or 5 stems over 3 feet tall per plot, have also been included here.

Of course, 100 percent stocking is not necessary. In older stands, the number of trees is frequently reduced by thinning to stimulate more rapid growth of the residuals. No yield is lost so long as the number of trees is not reduced below the level required for full site occupancy. This level, often referred to as the **B** level in stocking guides, is about 60 percent of normal stocking. Thus, any stand that has at least 60 percent stocking when it reaches merchantable size would be considered satisfactory. The 60 percent figure has therefore been used as the breaking point between satisfactory and unsatisfactory stocking of reproduction plots as well.

The nine sample plots used in this study would not provide an adequate sample on which to evaluate regeneration stocking of an entire clearcut, but were considered satisfactory here because the total area evaluated was limited to the ½ acre inside (or similar area outside) the deer exclosure.

RESULTS AND DISCUSSION

Older Clearcuts

There were three older clearcuts (15 to 16 years since cutting) available with satisfactory exclosures, and all of these had been examined once before, when they were 4 to 5 years old. Jordan *(1967)* has published the data from the earlier survey in these three cuttings.

Summaries of the average number of stems of various sizes are presented in table 2 for both the current and previous inventories. Total number of stems did not differ significantly between fenced and unfenced areas in 1960 and still did not in 1971 if all commercial species are considered. However, by 1971, the total number of preferred species had been significantly reduced by deer browsing. Preferential feeding has apparently affected the preferred species, producing a change in species composition of the unfenced areas—toward larger proportions of species such as beech and black birch and noncommercial striped maple.

The influence of deer on species composition is most obvious in the effect on noncommercial pin cherry (table 3). This species has been virtually eliminated from the unfenced areas by browsing.

Differences between fenced and unfenced areas in the numbers of stems over 3 feet tall, or over 5 feet tall, were quite large in 1960. Although differences still exist, they were much less dramatic by 1971 (table 2).

Regeneration stocking was much reduced by browsing in the unfenced areas (table 4). Although fenced portions of all three clearcuts are satisfactorily stocked, the unfenced portion of only one of the three clearcuts can be considered satisfactory. One of the other unfenced areas might be considered marginal, as it does have at least 1 commercial (but not preferred) stem per plot over 5 feet tall on 60 percent of the plots.

Experience and observation suggest that 5 stems per plot over 5 feet tall is adequate stocking at 15 to 16 years of age to insure the survival of 1 stem per plot when the stand reaches merchantable size. Assuming

Table 2.—Average number of stems in 15- to 16-year-old clearcuts

(Thousand per acre)

Size of stems	Fenced	Unfenced
PREFERRED SPECIES		
1960:		
Over 5 feet	0.5	0.1
Over 3 feet	2.4	0.4
All sizes	24.9	27.1
1971:		
Over 5 feet:	2.7	1.8
Over 3 feet	3.7	2.2
All sizes	12.0	8.8
COMMERCIAL SPECIES		
1960:		
Over 5 feet	0.6	0.1
Over 3 feet	2.7	0.5
All sizes	25.4	27.6
1971:		
Over 5 feet	3.7	2.2
Over 3 feet	4.5	3.0
All Sizes	11.6	11.8

Table 3.—Number of pin cherry stems in 15- to 16-year-old clearcuts

(Thousand per acre)

Item	Fenced	Unfenced
Number present 1960	4.1	0.2
Number present 1971	1.8	0.2
Number over 5 feet in 1960	2.2	0.0
Number over 5 feet in 1971	1.8	0.0

Table 4.—Proportion of 15- to 16-year old clearcuts satisfactorily stocked

Stands in which at least 60 percent of plots are stocked with--	Fenced	Unfenced
	Percent	*Percent*
Preferred species:		
5 stems over 5 feet tall	100	0
2 stems over 5 feet tall	100	33
1 stem over 5 feet tall	100	33
Commercial species:		
5 stems over 5 feet tall	100	33
2 stems over 5 feet tall	100	33
1 stem over 5 feet tall	100	67

that this is an appropriate measure of stocking in 15- to 16-year-old stands, I examined the 1960 data on these three clearcuts to see what measure of stocking at 4 to 5 years of age provides the most reliable means of predicting which clearcuts will be satisfactorily stocked when they reach 15 to 16 years of age. Data from a few of the many stocking criteria examined are shown in table 5.

Regressions run on the various stocking criteria provide a crude measure of the effectiveness of each criterion (table 5). Several of the criteria shown seem to have some value as predictors. However, the one that seems to have most potential value is the proportion of plots that contained at least 2 stems over 3 feet tall or 100 seedlings of any size. This criterion is the only one that showed complete agreement with the stocking evaluations at 15 to 16 years of age. That is, all areas at least 60 percent stocked at age 4 to 5 years on the basis of this criterion were still at least 60 percent stocked at age 15 to 16 years; and all areas less than 60 percent stocked were still less than 60 percent stocked at age 15 to 16 years.

No other criterion performed as well, although one other one actually had a higher R^2 value. A considerable amount of additional data from other areas will be needed to provide rigorous tests and permit selection of the best criterion. But in the interim, stocking of Allegheny hardwood reproduction in 4- to 5-year-old clearcuts can probably be evaluated with reasonable accuracy on the basis of the proportion of 6-foot-radius plots stocked with at least 2 commercial stems over 3 feet tall or 100 stems of any size.

Recent Clearcuts

There were 10 exclosures in recent clearcuts (5 to 6 years old), and there was much variation among them in the impact that deer had on regeneration. Two of the 10 areas were almost completely bare of trees except where they had been protected by the deer exclosure (fig. 1). The other eight areas showed the influence of deer in varying degrees.

The total number of stems found in the unfenced areas averaged slightly less (not significant) than in the fenced areas (18,400 versus 20,900). The impact of deer is more apparent if only stems over 5 feet tall are considered. Unfenced areas averaged 36 percent fewer stems of this size than the fenced areas (4,600 versus 7,200). If only commercial species are considered, the figures are 3,200 versus 5,300; and this difference was statistically significant.

The reduction in number of stems over 5 feet tall as a result of browsing occurred in

Table 5.—Regeneration stocking of commercial species was judged by various stocking criteria

Plots	Age 15 to 16 years: proportion of plots satisfactorily stocked[1]	Age 4 to 5 years[2]							
		Total stems	Stems over 3 feet tall	Proportion of plots stocked with at least--					
				5 stems	10 stems	100 stems	2 stems over 3 feet tall	2 stems over 3 feet or 100 stems	5 stems over 3 feet tall
	Percent	*Thousands per acre*		*Percent*					
Fenced:									
Chappel Fork	100	61.8	2.4	100	100	75	67	83	58
Cherry Grove	78	9.6	3.7	64	45	9	64	64	45
Silver Creek	78	4.7	2.0	67	42	0	67	67	33
Unfenced:									
Chappel Fork	67	76.6	1.1	100	100	92	42	92	25
Cherry Grove	55	3.5	.3	75	33	0	25	25	0
Silver Creek	31	2.6	.1	50	25	0	8	8	0
Coefficient of determination (R^2) on stocking at age 15 to 16 years		0.66 *	0.87 **	0.50	0.67 *	0.60	0.95 **	0.87 **	0.87 **

[1] A satisfactorily stocked plot is one containing at least 5 stems of commercial species over 5 feet tall.
[2] * Significant at 0.05 level; ** significant at 0.01 level.

Figure 1.—Deer browsing has completely eliminated tree regeneration outside (left of this photo) this fenced deer exclosure.

all species except striped maple and aspen. Pin cherry and sugar maple were browsed especially hard; large stems of both these species were virtually eliminated in the unfenced areas (table 6).

Stocking levels, as measured by a variety of criteria, differed significantly between fenced and unfenced areas (table 7). Although the different criteria produced slightly different results, somewhere between 10 and 40 percent of the areas studied have failed to regenerate satisfactorily as a direct result of deer browsing. That is, regeneration is satisfactory inside the exclosure and unsatisfactory outside the exclosure in 10 to 40 percent of the clearcuts.

Deer browsing had a greater impact on the preferred timber species than on all commercial species. For example, the proportion of clearcuts on which 60 percent of the plots were stocked with at least 2 stems over 3 feet tall was reduced by browsing from 90 to 50 percent on preferred species, but was reduced only from 90 to 70 percent if all commercial species are counted (table 7).

Data in table 7 also indicate that somewhere between 40 and 80 percent of the clearcuts will regenerate satisfactorily in spite of deer browsing (outside the exclosure). There are no data available for these stands before cutting, so the factors responsible for the success of some stands and the failure of others cannot be determined. However, extensive surveys performed by Grisez and Peace *(1973)* have shown that stands containing abundant advance regeneration before cutting have a high probability of regenerating satisfactorily even in the presence of deer browsing, while those with sparse advance regeneration are likely to fail. Much of the difference in stands observed here can probably be attributed to such differences in advance regeneration.

Average height of the tallest stem of all preferred species was reduced 38 percent in the unfenced areas, from 9.2 to 5.7 feet. Average height of the tallest stem of all commercial species was reduced 41 percent, from 11.6 to 6.8 feet (table 8). Both of these differences were statistically significant.

The average area occupied by groundcover vegetation did not differ appreciably

Table 6.—Average number of stems in 5- to 6-year-old clearcuts

(Thousands of stems per acre)

Species	Fenced			Unfenced		
	Over 5 feet	Under 5 feet	All sizes	Over 5 feet	Under 5 feet	All sizes
Black cherry	2.2	7.4	9.7	1.8	7.5	9.3
Suger maple	.3	.7	1.0	.0	.7	.7
Red maple	.4	1.8	2.3	.3	1.8	2.0
White ash	.4	1.0	1.4	.1	.6	.7
Beech	1.0	.9	1.9	.3	.4	.6
Birch	1.0	.7	1.6	.8	.9	1.7
Aspen	.2	.1	.3	.2	.1	.3
Pin cherry	1.2	.2	1.5	.1	.5	.6
Striped maple	.2	.1	.3	.7	.4	1.1
Others	.3	.8	.9	.3	.9	1.4
All species	7.2	13.7	20.9	4.6	13.8	18.4

Table 7.—Proportion of 5- to 6-year-old clearcuts satisfactorily stocked

Clearcuts in which at least 60 percent of plots are stocked with--	Fenced	Unfenced
	Percent	*Percent*
Preferred species:		
5 stems over 3 feet tall	70	40
2 stems over 3 feet tall	90	50
10 stems any size	70	60
5 stems any size	90	60
2 stems over 3 feet *or* 100 stems any size	90	50
2 stems over 3 feet *or* 25 stems any size	90	50
Commercial species:		
5 stems over 3 feet tall	90	50
2 stems over 3 feet tall	90	70
10 stems any size	90	60
5 stems any size	90	80
2 stems over 3 feet *or* 100 stems any size	90	70
2 stems over 3 feet *or* 25 stems any size	90	70

between the fenced and unfenced areas, but there were shifts in species abundance. Browsing reduced *Rubus* spp. considerably in the unfenced areas, while grasses and sedges spread to fill this void. These differences between fenced and unfenced areas were significant at the 10 percent level. Coverage of ferns and other ground-cover species was similar both inside and outside the exclosure (table 9). However, these average figures conceal some large differences that occurred in the individual areas. For example, the two areas in which tree seedlings were almost completely eliminated outside the exclosures had been taken over completely by herbaceous plants; primarily grasses and sedges, ferns, and tall plants such as goldenrod and aster (fig. 2).

All Clearcuts Combined

To provide a measure of the impact of deer browsing on Allegheny hardwood regeneration, all 13 clearcuts were grouped together, and stocking was evaluated on the basis of the most promising criterion. Those in which at least 60 percent of the plots were stocked with at least 2 stems over 3 feet tall, or 100 stems of any size at age 4 to 6 years, were judged to have regenerated satisfactorily;

Figure 2.—This 10-year old clearcut has failed to regenerate to tree species. This area is completely dominated by herbaceous plants such as grasses, ferns, goldenrod, and aster.

Table 8.—Average heights of tallest stem per plot in 5- to 6-year-old clearcuts

Species	Fenced	Unfenced
	Feet	*Feet*
Black cherry	9.0	4.1
Sugar maple	3.4	1.0
Red maple	4.8	3.6
White ash	3.4	2.5
Any preferred species	9.2	5.7
Any commercial species	11.6	6.8

Table 9.—Ground cover in 5- to 6-year-old clearcuts

Ground cover	Fenced	Unfenced
AVERAGE COVERAGE (percent)		
Rubus	46	27
Ferns	14	16
Grasses, sedges	6	15
All species	63	58
PROPORTION OF PLOTS WITH OVER 30-PERCENT COVERAGE (percent)		
Rubus	57	39
Ferns	23	20
Grasses, sedges	6	20
All species	91	83

those with lower stocking were judged unsatisfactory:

	Preferred species	*Commercial species*
Fenced	92	92
Unfenced	50	67

On this basis, deer browsing has resulted in unsatisfactory stocking of preferred species on 42 percent of the clearcuts examined. It has resulted in unsatisfactory stocking of any commercial timber species on 25 percent of the clearcuts examined (table 10).

A few areas (8 percent) failed to regenerate satisfactorily even where protected

Table 10.—Summary of regeneration success or failure

Success or failure	Preferred Species	Commercial Species
	Percent	*Percent*
Clearcuts successful in spite of deer browsing	50	67
Clearcuts failed because of deer browsing	42	25
Clearcuts failed because of other causes	8	8

from deer browsing (inside the exclosure). However, deer browsing may be responsible for these failures, too, to the extent that browsing may have reduced the number of advance seedlings present before cutting, and thus contributed to the failure before the fence was erected.

CONCLUSIONS

The following conclusions seem warranted:

- Browsing by white-tailed deer reduces the stocking of tree species in clearcut areas on the Allegheny Plateau of Pennsylvania and New York. Regeneration failures can be attributed directly to deer browsing in 25 to 40 percent of those areas in which no special attention has been given to advance reproduction.

- Successful regeneration can be obtained on many areas in spite of deer browsing; between ½ and ⅔ of the areas studied here have regenerated satisfactorily without protection from deer. Although not demonstrated here, other studies have shown that the stands most likely to regenerate satisfactorily are those with abundant advance regeneration *(Grisez and Peace 1973)*. These same studies show that over 90 percent of the areas clearcut will regenerate satisfactorily in spite of deer browsing if advance reproduction is abundant before cutting.

- Pin cherry is the species most severely affected by deer browsing. In unfenced clearcuts, pin cherry has been nearly eliminated by browsing. Sugar maple is also selectively reduced by browsing, while beech, birch, and striped maple often increase in proportion to other species in clearcuts subjected to deer browsing.

- Regeneration in areas cut 4 to 5 years previously can be judged satisfactory if 60 percent of the 6-foot-radius sample plots examined are stocked with at least 2 desirable stems over 3 feet tall *or* at least 100 desirable stems of any size.

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MANUSCRIPT RECEIVED FOR PUBLICATION 3 APRIL 1974

Abstract

Dry lumber prices were applied to green and air-dried lumber that was measured with a dry board rule. Values were summed by species, lumber grade, and thickness class. Differences between green and air-dried lumber value have been termed value losses and are given in dollars and in percentages. The percentages have been separated into loss due to shrinkage and loss due to degrade. Data for 10 hardwood species are included.

Value Loss of Hardwood Lumber During Air-Drying

Leland F. Hanks and
Margaret K. Peirsol

INTRODUCTION

In a recently reported study *(Gammon 1971)* the lumber volume loss and grade change during air-drying of 10 hardwood species was presented. We used the same basic data to determine the lumber value loss during air-drying.

These lumber volume and value loss figures should be useful to sawmill operators for estimating such losses at their mills. The figures may also be used as a standard with which to compare actual data on drying performance at individual mills.

STUDY METHODS

The data for this report were gathered in conjunction with studies of lumber yield in relation to log and tree grades conducted at sawmills throughout the East. Each board was measured with a dry board rule and graded by an inspector from the National Hardwood Lumber Association. This was done at the time of sawing and again when the lumber had been air-dried to approximately 20 percent moisture content. Green boards were numbered for future identification. Thickness, surface measure, and board number were recorded at both green and dry gradings.

For each species, green grade, and thickness class, we calculated a potential value by applying dry lumber prices to the green lumber volumes. The Hardwood Market Report *(Lemsky)* for March 10, 1973 was the source for price information. Actual dry lumber value was determined by applying dry prices to the dry lumber volumes. The difference between the potential and actual dry value will be referred to as total value loss during air drying. Value loss per thousand board feet and percent loss were also determined.

RESULTS

Table 1 contains the value loss information by lumber grade and thickness for the 10 species. The results for northern red, scarlet, and black oak are also presented combined as these species are not separated in the lumber market.

The relationship between lumber thickness and value loss was determined by species (table 2).

Table 1.—Value loss during air-drying by species, lumber, grade, and thickness.

Lumber grade	Rough green Thickness	Rough green Volume	Potential value	Actual dry value	Value loss Total[a]	Value loss Per MBF[a]	Value loss Due to shrinkage	Value loss Due to[b] degrade	Value loss Total[a]
	Inches	*Fbm*	— — — — — *Dollars* — — — — —				— — — *Percent* — — —		
				BASSWOOD					
FAS	4/4	5789	1620.92	1524.09	96.83	16.73	4.6	1.4	6.0
	6/4	369	107.01	99.14	7.87	21.33	6.8	0.6	7.4
	Total	6158	1727.93	1623.23	104.70	17.00	4.7	1.4	6.1
SELECTS	4/4	5053	1339.04	1245.52	93.52	18.51	4.5	2.5	7.0
	6/4	668	183.70	167.34	16.36	24.49	6.1	2.8	8.9
	Total	5721	1522.74	1412.86	109.88	19.21	4.7	2.5	7.2
NO. 1C	4/4	10098	1868.13	1726.15	141.98	14.06	5.3	2.3	7.6
	5/4	219	41.61	37.18	4.43	20.23	8.2	2.4	10.6
	6/4	504	98.28	91.76	6.52	12.94	7.9	+1.3	6.6
	Total	10821	2008.02	1855.09	152.93	14.13	5.5	2.1	7.6
NO. 2C	4/4	13793	1379.30	1330.28	49.02	3.55	4.1	+0.5	3.6
	5/4	272	27.74	24.38	3.36	12.35	11.0	1.1	12.1
	Total	14065	1407.04	1354.66	52.38	3.72	4.2	+0.5	3.7
NO. 3C	4/4	3466	246.09	241.89	4.20	1.21	3.4	+1.7	1.7
Grand Total		40231	6911.82	6487.73	424.09	10.54	4.6	1.5	6.1
				RED MAPLE					
FAS	4/4	3760	977.60	945.51	32.09	8.53	2.0	1.3	3.3
	5/4	1220	323.30	299.24	24.06	19.72	2.9	4.5	7.4
	6/4	1387	374.49	362.67	11.82	8.52	2.3	0.9	3.2
	8/4	2050	563.75	552.89	10.86	5.30	1.8	0.1	1.9
	Total	8417	2239.14	2160.31	78.83	9.37	2.1	1.4	3.5
FAS1F	4/4	3471	867.75	832.17	35.58	10.25	2.3	1.8	4.1
	5/4	1146	292.23	263.36	28.87	25.19	3.8	6.1	9.9
	6/4	955	248.30	234.83	13.47	14.10	2.6	2.8	5.4
	Total	5572	1408.28	1330.36	77.92	13.98	2.7	2.8	5.5
SELECTS	4/4	1558	373.92	351.52	22.40	14.38	3.2	2.8	6.0
	5/4	773	189.38	180.34	9.04	11.69	3.0	1.8	4.8
	6/4	277	69.25	65.89	3.36	12.13	3.6	1.3	4.9
	8/4	864	220.32	216.24	4.08	4.72	2.3	+0.4	1.9
	Total	3472	852.87	813.99	38.88	11.20	2.9	1.7	4.6
NO. 1C	4/4	6914	1382.80	1314.94	67.86	9.81	2.7	2.2	4.9
	5/4	2074	425.17	402.08	23.09	11.13	3.3	2.1	5.4
	6/4	1035	217.35	211.37	5.98	5.78	2.9	+0.1	2.8
	8/4	702	157.95	155.79	2.16	3.08	1.3	0.1	1.4
	Total	10725	2183.27	2084.18	99.09	9.24	2.8	1.7	4.5
NO. 2A	4/4	9608	1152.96	1121.18	31.78	3.31	2.6	0.2	2.8
	5/4	1934	235.95	230.62	5.33	2.76	3.5	+1.2	2.3
	Total	11542	1388.91	1351.80	37.11	3.22	2.8	+0.1	2.7
NO. 2B	4/4	7285	728.50	714.24	14.26	1.96	2.8	+0.8	2.0
	5/4	1738	177.28	177.20	.08	.05	2.5	+2.5	0.0
	Total	9023	905.78	891.44	14.34	1.59	2.7	+1.1	1.6
NO. 3A	4/4	1954	185.63	182.67	2.96	1.51	3.2	+1.6	1.6
	5/4	335	32.16	31.75	.41	1.22	5.1	+3.8	1.3
	Total	2289	217.79	214.42	3.37	1.47	3.5	+2.0	1.5
NO. 3B	4/4	861	77.49	76.62	.87	1.01	2.6	+1.5	1.1
Grand Total		51901	9273.53	8923.12	350.41	6.75	2.7	1.1	3.8

CONTINUED

Table 1.—Continued

Lumber grade	Rough green: Thickness	Rough green: Volume	Potential value	Actual dry value	Value loss: Total[a]	Value loss: Per MBF[a]	Value loss: Due to shrinkage	Value loss: Due to[b] degrade	Value loss: Total[a]
	Inches	*Fbm*	— — — — — *Dollars* — — — — —				— — — *Percent* — — —		
				YELLOW BIRCH					
FAS	4/4	3734	1418.92	1298.13	120.79	32.35	4.1	4.4	8.5
	5/4	3028	1180.92	1121.37	59.55	19.67	4.1	0.9	5.0
	6/4	500	200.00	191.85	8.15	16.30	3.6	0.5	4.1
	Total	7262	2799.84	2611.35	188.49	25.96	4.1	2.6	6.7
FAS1F	4/4	2287	846.19	743.67	102.52	44.83	4.2	7.9	12.1
	5/4	1925	731.50	681.18	50.32	26.14	2.3	4.6	6.9
	6/4	608	237.12	225.62	11.50	18.91	4.4	0.4	4.8
	Total	4820	1814.81	1650.47	164.34	34.10	3.5	5.6	9.1
SELECTS	4/4	912	328.32	291.65	36.67	40.21	4.5	6.7	11.2
	5/4	309	114.33	108.26	6.07	19.64	2.6	2.7	5.3
	Total	1221	442.65	399.91	42.74	35.00	4.0	5.7	9.7
NO. 1C	4/4	9127	1962.30	1854.44	107.86	11.82	4.1	1.4	5.5
	5/4	3866	850.52	801.33	49.19	12.72	3.8	2.0	5.8
	6/4	712	181.56	176.28	5.28	7.42	3.1	+0.2	2.9
	Total	13705	2994.38	2832.05	162.33	11.84	3.9	1.5	5.4
NO. 2C	4/4	8328	999.36	966.15	33.21	3.99	3.8	+0.5	3.3
	5/4	3240	405.00	391.43	13.57	4.19	3.3	0.1	3.4
	6/4	287	38.74	38.72	.02	.07	2.8	+2.7	0.1
	Total	11855	1443.10	1396.30	46.80	3.95	3.6	+0.4	3.2
NO. 3AC	4/4	5518	562.84	536.16	26.68	4.84	3.8	0.9	4.7
	5/4	1312	135.14	131.58	3.56	2.71	3.0	+0.4	2.6
	Total	6830	697.98	667.74	30.24	4.43	3.6	0.7	4.3
NO. 3BC	4/4	4625	416.25	398.62	17.63	3.81	3.8	0.4	4.2
	5/4	669	60.88	57.82	3.06	4.57	2.2	2.8	5.0
	Total	5294	477.13	456.44	20.69	3.91	3.6	0.7	4.3
Grand Total		50987	10669.89	10014.26	655.63	12.86	3.5	2.6	6.1
				SUGAR MAPLE					
FAS	4/4	896	268.80	250.44	18.36	20.49	2.5	4.3	6.8
	5/4	4410	1367.10	1256.60	110.50	25.06	4.4	3.7	8.1
	8/4	988	355.68	334.31	21.37	21.63	1.6	4.4	6.0
	Total	6294	1991.58	1841.35	150.23	23.87	3.7	3.8	7.5
FAS1F	4/4	795	230.55	213.12	17.43	21.92	2.3	5.3	7.6
	5/4	4622	1386.60	1262.99	123.61	26.74	3.4	5.5	8.9
	8/4	1878	657.30	618.94	38.36	20.43	1.5	4.3	5.8
	Total	7295	2274.45	2095.05	179.40	24.59	2.8	5.1	7.9
SELECTS	4/4	1210	338.80	293.78	45.02	37.21	2.1	11.2	13.3
	5/4	685	198.65	191.66	6.99	10.20	2.6	0.9	3.5
	Total	1895	537.45	485.44	52.01	27.45	2.3	7.4	9.7
NO. 1C	4/4	5615	1179.99	1087.05	92.94	16.55	2.7	5.2	7.9
	5/4	11053	2431.66	2218.40	213.26	19.29	3.6	5.2	8.8
	8/4	3288	838.44	760.17	78.27	23.80	1.5	7.8	9.3
	Total	19956	4450.09	4065.62	384.47	19.27	3.0	5.6	8.6
NO. 2C	4/4	6301	850.64	817.88	32.76	5.20	2.7	1.2	3.9
	5/4	7357	1007.91	956.70	51.21	6.96	3.7	1.4	5.1
	8/4	1664	232.96	236.28	+3.32	+2.00	1.3	+2.7	+1.4
	Total	15322	2091.51	2010.86	80.65	5.26	3.0	0.9	3.9
NO. 3AC	4/4	4943	568.44	542.72	25.72	5.20	2.5	2.0	4.5
	5/4	2301	269.22	225.25	43.97	19.11	3.8	12.5	16.3
	Total	7244	837.66	767.97	69.69	9.62	2.9	5.4	8.3
NO. 3BC	4/4	5827	524.43	513.24	11.19	1.92	2.5	+0.4	2.1
	5/4	1074	97.73	83.81	13.92	12.96	2.1	12.1	14.2
	Total	6901	622.16	597.05	25.11	3.64	2.4	1.6	4.0
Grand Total		64907	12804.90	11863.34	941.56	14.51	3.0	4.4	7.4

CONTINUED

Table 1.—Continued

Lumber grade	Rough green Thickness	Volume	Potential value	Actual dry value	Value loss Total[a]	Per MBF[a]	Due to shrinkage	Due to[b] degrade	Total[a]
	Inches	*Fbm*	— — — — — *Dollars* — — — — —				— — — *Percent* — — —		
				YELLOW-POPLAR					
FAS	4/4	1434	408.69	381.58	27.11	18.91	2.6	4.0	6.6
SELECTS	4/4	1511	415.52	364.10	51.42	34.03	3.0	9.4	12.4
	6/4	316	93.22	87.50	5.72	18.10	4.7	1.4	6.1
	Total	1827	508.74	451.60	57.14	31.28	3.3	7.9	11.2
SAPS	4/4	3836	1016.54	951.20	65.34	17.03	3.1	3.3	6.4
	6/4	845	240.82	227.42	13.40	15.86	3.7	1.9	5.6
	Total	4681	1257.36	1178.62	78.74	16.82	3.2	3.1	6.3
NO. 1C	4/4	24543	5276.74	4875.86	400.88	16.33	3.4	4.2	7.6
	6/4	4629	1064.67	1011.52	53.15	11.48	4.2	0.8	5.0
	Total	29172	6341.41	5887.38	454.03	15.56	3.8	3.4	7.2
NO. 2AC	4/4	27688	3876.32	3676.44	199.88	7.22	3.8	1.4	5.2
	6/4	2547	369.32	372.04	+2.72	+1.07	3.7	+4.4	+0.7
	Total	30235	4245.64	4048.48	197.16	6.52	3.8	0.8	4.6
NO. 2BC	4/4	17633	1763.30	1732.09	31.21	1.77	3.4	+1.6	1.8
NO. 3C	4/4	1843	165.87	157.80	8.07	4.38	2.8	2.1	4.9
Grand Total		86825	14691.01	13837.55	853.46	9.83	2.2	3.6	5.8
				BLACK OAK					
FAS	4/4	580	176.90	168.45	8.45	14.57	1.7	3.1	4.8
	5/4	9506	2946.86	2822.76	124.10	13.05	2.4	1.8	4.2
	Total	10086	3123.76	2991.21	132.55	13.14	2.3	1.9	4.2
FAS1F	4/4	992	292.64	267.26	25.38	25.58	2.7	6.0	8.7
	5/4	6684	2005.20	1852.47	152.73	22.85	3.0	4.6	7.6
	Total	7676	2297.84	2119.73	178.11	23.20	3.0	4.8	7.8
SELECTS	4/4	297	84.64	74.46	10.18	34.28	5.4	6.6	12.0
	5/4	1016	294.64	272.10	22.54	22.19	3.3	4.4	7.7
	Total	1313	379.28	346.56	32.72	24.92	3.8	4.8	8.6
NO. 1C	4/4	7542	1546.11	1451.79	94.32	12.51	2.7	3.4	6.1
	5/4	14406	3169.32	3008.37	160.95	11.17	3.2	1.9	5.1
	Total	21948	4715.43	4460.16	255.27	11.63	3.0	2.4	5.4
NO. 2C	4/4	8791	1098.88	1043.94	54.94	6.25	2.4	2.6	5.0
	5/4	5225	658.35	646.65	11.70	2.24	4.0	+2.2	1.8
	Total	14016	1757.23	1690.59	66.64	4.75	3.0	0.8	3.8
SW	4/4	2067	237.70	228.92	8.78	4.25	3.1	0.6	3.7
	5/4	590	68.44	66.43	2.01	3.41	3.1	+0.2	2.9
	Total	2657	306.14	295.35	10.79	4.06	3.1	0.4	3.5
NO. 3AC	4/4	6420	738.30	706.11	32.19	5.01	2.0	2.4	4.4
	5/4	910	105.56	98.74	6.82	7.49	5.9	0.6	6.5
	Total	7330	843.86	804.85	39.01	5.32	2.5	2.1	4.6
NO. 3BC	4/4	2629	236.61	235.70	.91	.35	1.6	+1.2	0.4
Grand Total		67655	13660.15	12944.15	716.00	10.58	2.8	2.4	5.2

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Table 1.—Continued

Lumber grade	Rough green: Thickness	Rough green: Volume	Potential value	Actual dry value	Value loss: Total[a]	Value loss: Per MBF[a]	Value loss: Due to shrinkage	Value loss: Due to degrade[b]	Value loss: Total[a]
	Inches	*Fbm*	*Dollars*				*Percent*		
NORTHERN RED OAK									
FAS	4/4	8861	2702.60	2494.98	207.62	23.43	3.5	4.2	7.7
	5/4	28365	8793.15	8238.00	555.15	19.57	3.4	2.9	6.3
	6/4	5570	1782.40	1694.84	87.56	15.72	3.5	1.4	4.9
	Total	42796	13278.15	12427.82	850.33	19.87	3.4	3.0	6.4
FAS1F	4/4	7549	2226.96	1970.97	255.99	33.91	3.1	8.4	11.5
	5/4	11920	3576.00	3251.75	324.25	27.20	3.9	5.2	9.1
	6/4	1312	406.72	374.58	32.14	24.50	5.7	2.2	7.9
	Total	20781	6209.68	5597.30	612.38	29.47	3.7	6.2	9.9
SELECTS	4/4	2251	641.54	581.89	59.65	26.50	3.2	6.1	9.3
	5/4	2490	722.10	672.82	49.28	19.79	3.2	3.6	6.8
	Total	4741	1363.64	1254.71	108.93	22.98	3.2	4.8	8.0
NO. 1C	4/4	29404	6027.82	5591.62	436.20	14.83	3.4	3.8	7.2
	5/4	20386	4484.92	4157.19	327.73	16.08	4.3	3.0	7.3
	6/4	1132	271.68	243.62	28.06	24.79	7.6	2.7	10.3
	Total	50922	10784.42	9992.43	791.99	15.55	3.9	3.4	7.3
NO. 2C	4/4	28386	3548.25	3589.42	+41.17	+1.45	3.3	+4.5	+1.2
	5/4	4976	626.98	570.65	56.33	11.32	9.8	+0.8	9.0
	Total	33362	4175.23	4160.07	15.16	0.45	4.3	+3.9	0.4
NO. 3AC	4/4	16160	1858.40	1800.80	57.60	3.56	3.4	+0.3	3.1
	5/4	1099	127.48	108.09	19.39	17.64	11.7	3.5	15.2
	Total	17259	1985.88	1908.89	76.99	4.46	3.9	0.0	3.9
NO. 3BC	4/4	7698	692.82	701.28	+8.46	+1.10	3.2	+4.4	+1.2
	5/4	447	40.68	38.79	1.89	4.23	12.1	+7.5	4.6
	Total	8145	733.50	740.07	+6.57	+0.81	3.7	+4.6	+0.9
Grand Total		178006	38530.50	36081.29	2449.21	13.76	3.8	2.6	6.4
SCARLET OAK									
FAS	5/8	1288	315.56	288.02	27.54	21.38	5.0	3.7	8.7
	4/4	923	281.52	262.20	19.32	20.93	3.0	3.9	6.9
	5/4	1059	328.29	312.36	15.93	15.04	2.2	2.7	4.9
	Total	3270	925.37	862.58	62.79	19.20	3.5	3.3	6.8
FAS1F	5/8	808	189.88	168.86	21.02	26.01	5.4	5.7	11.1
	4/4	715	210.92	190.57	20.35	28.46	2.9	6.7	9.6
	5/4	760	228.00	198.70	29.30	38.55	2.6	10.3	12.9
	Total	2283	628.80	558.13	70.67	30.95	3.7	7.5	11.2
SELECTS	4/4	260	74.10	67.02	7.08	27.23	4.2	5.4	9.6
NO. 1C	5/8	5323	851.68	817.29	34.39	6.46	4.3	+0.3	4.0
	4/4	6247	1280.64	1153.71	126.93	20.32	2.7	7.2	9.9
	5/4	1535	337.70	318.16	19.54	12.73	2.5	3.3	5.8
	Total	13105	2470.02	2289.16	180.86	13.80	3.3	4.0	7.3
NO. 2C	5/8	1449	144.90	143.40	1.50	1.04	5.2	+4.2	1.0
	4/4	10496	1305.75	1293.26	12.49	1.19	2.7	+1.7	1.0
	Total	11945	1450.65	1436.66	13.99	1.17	3.0	+2.0	1.0
NO. 3AC	5/8	277	24.93	24.90	.03	0.11	4.7	+4.6	0.1
	4/4	11072	1273.28	1218.96	54.32	4.91	2.8	1.5	4.3
	Total	11349	1298.21	1243.86	54.35	4.79	2.9	1.3	4.2
NO. 3BC	4/4	7328	659.52	649.72	9.80	1.34	2.7	+1.2	1.5
Grand Total		49540	7506.67	7107.13	399.54	8.06	3.1	2.2	5.3

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Table 1.—Continued

Lumber grade	Rough green: Thickness	Rough green: Volume	Potential value	Actual dry value	Value loss: Total[a]	Value loss: Per MBF[a]	Value loss: Due to shrinkage	Value loss: Due to[b] degrade	Value loss: Total[a]
	Inches	*Fbm*	— — — — — *Dollars* — — — — —				— — — *Percent* — — —		
BLACK OAK, NORTHERN RED OAK, AND SCARLET OAK COMBINED									
FAS	5/8	1288	315.56	288.02	27.54	21.38	5.0	3.7	8.7
	4/4	10364	3161.02	2925.63	235.39	22.71	3.3	4.1	7.4
	5/4	38930	12068.30	11373.12	695.18	17.86	3.1	2.7	5.8
	6/4	5570	1782.40	1694.84	87.56	15.72	3.5	1.4	4.9
	Total	56152	17327.28	16281.61	1045.67	18.62	3.2	2.8	6.0
FAS1F	5/8	808	189.88	168.86	21.02	26.01	11.1	0.0	11.1
	4/4	9256	2730.52	2428.80	301.72	32.60	3.1	7.9	11.0
	5/4	19364	5809.20	5302.92	506.28	26.15	3.5	5.2	8.7
	6/4	1312	406.72	374.58	32.14	24.50	5.7	2.2	7.9
	Total	30740	9136.32	8275.16	861.16	28.01	3.5	5.9	9.4
SELECTS	4/4	2808	800.28	723.37	76.91	27.39	3.6	6.0	9.6
	5/4	3506	1016.74	944.92	71.82	20.48	3.2	3.9	7.1
	Total	6314	1817.02	1668.29	148.73	23.56	3.4	4.8	8.2
NO. 1C	5/8	5323	851.68	817.29	34.39	6.46	4.0	0.0	4.0
	4/4	43193	8854.57	8197.12	657.45	15.22	3.2	4.2	7.4
	5/4	36327	7991.94	7483.72	508.22	13.99	3.8	2.6	6.4
	6/4	1132	271.68	243.62	28.06	24.79	7.6	2.7	10.3
	Total	85975	17969.87	16741.75	1228.12	14.28	3.6	3.2	6.8
NO. 2C	5/8	1449	144.90	143.40	1.50	1.04	5.2	+4.2	1.0
	4/4	47673	5952.88	5926.62	26.26	.55	3.0	+2.6	0.4
	5/4	10201	1285.33	1217.30	68.03	6.67	6.8	+1.5	5.3
	Total	59323	7383.11	7287.32	95.79	1.61	3.7	+2.4	1.3
SW	4/4	2067	237.70	228.92	8.78	4.25	3.1	0.6	3.7
	5/4	590	68.44	66.43	2.01	3.41	3.1	+0.2	2.9
	Total	2657	306.14	295.35	10.79	4.06	3.1	0.4	3.5
NO. 3AC	5/8	277	24.93	24.90	.03	0.11	4.7	+4.6	0.1
	4/4	33652	3869.98	3725.87	144.11	4.28	2.9	0.8	3.7
	5/4	2009	233.04	206.83	26.21	13.05	9.1	2.1	11.2
	Total	35938	4127.95	3957.60	170.35	4.74	3.3	0.8	4.1
NO. 3BC	4/4	17655	1588.95	1586.70	2.25	.13	2.7	+2.6	0.1
	5/4	447	40.68	38.79	1.89	4.23	12.1	+7.5	4.6
	Total	18102	1629.63	1625.49	4.14	.23	3.0	+2.7	0.3
Grand Total		295201	59697.32	56132.57	3564.75	12.08	3.5	2.5	6.0

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Table 1.—Continued

Lumber grade	Rough green: Thickness	Rough green: Volume	Potential value	Actual dry value	Value loss: Total[a]	Value loss: Per MBF[a]	Value loss: Due to shrinkage	Value loss: Due to[b] degrade	Value loss: Total[a]
	Inches	*Fbm*	*Dollars*				*Percent*		
				CHESTNUT OAK					
FAS	4/4	1205	361.50	320.11	41.39	34.35	6.3	5.1	11.4
	5/4	910	277.55	251.38	26.17	28.76	4.5	4.9	9.4
	6/4	1602	512.64	473.54	39.10	24.41	3.0	4.6	7.6
	Total	3717	1151.69	1045.03	106.66	28.70	4.4	4.9	9.3
FAS WHND	4/4	3230	629.85	577.64	52.21	16.16	4.6	3.7	8.3
	5/4	1645	353.68	324.82	28.86	17.54	5.2	3.0	8.2
	6/4	7823	1721.06	1622.00	99.06	12.66	3.8	2.0	5.8
	Total	12698	2704.59	2524.46	180.13	14.19	4.2	2.5	6.7
FAS1F	4/4	1140	330.60	305.08	25.52	22.39	3.7	4.0	7.7
	5/4	904	266.68	234.74	31.94	35.33	5.5	6.5	12.0
	6/4	2621	812.51	732.41	80.10	30.56	3.9	6.0	9.9
	Total	4665	1409.79	1272.23	137.56	29.49	4.2	5.6	9.8
FAS1F WHND	4/4	735	135.98	128.12	7.86	10.69	4.2	1.6	5.8
	5/4	540	110.70	109.27	1.43	2.65	3.0	+1.7	1.3
	6/4	1533	321.93	304.74	17.19	11.21	4.8	0.5	5.3
	Total	2808	568.61	542.13	26.48	9.43	4.3	0.4	4.7
SELECTS	4/4	436	122.08	109.62	12.46	28.58	4.4	5.8	10.2
	5/4	211	60.14	55.84	4.30	20.38	3.8	3.3	7.1
	Total	647	182.22	165.46	16.76	25.90	4.2	5.0	9.2
SEL WHND	4/4	201	35.18	34.87	.31	1.54	2.0	+1.1	0.9
NO. 1C	4/4	6000	1200.00	1101.90	98.10	16.35	4.8	3.4	8.2
	5/4	1973	414.33	383.71	30.62	15.52	5.6	1.8	7.4
	6/4	2823	649.29	607.20	42.09	14.91	2.8	3.7	6.5
	Total	10796	2263.62	2092.81	170.81	15.82	4.4	3.1	7.5
NO. 1C WHND	4/4	11154	1673.10	1565.96	107.14	9.61	4.1	2.3	6.4
	5/4	3398	560.67	530.23	30.44	8.96	4.2	1.2	5.4
	6/4	4146	746.28	712.37	33.91	8.18	3.5	1.0	4.5
	Total	18698	2980.05	2808.56	171.49	9.17	4.0	1.8	5.8
NO. 2C	4/4	9151	1143.88	1092.78	51.10	5.58	4.1	0.4	4.5
	5/4	574	77.49	67.73	9.76	17.00	11.8	0.8	12.6
	Total	9725	1221.37	1160.51	60.86	6.26	4.5	0.5	5.0
SW	4/4	11674	1400.88	1359.82	41.06	3.52	3.9	+1.0	2.9
	5/4	1712	222.56	216.57	5.99	3.50	5.5	+2.8	2.7
	6/4	733	98.96	102.32	+3.36	+4.58	3.5	+6.9	+3.4
	Total	14119	1722.40	1678.71	43.69	3.09	4.1	+1.6	2.5
NO. 3AC	4/4	14136	1625.64	1508.14	117.50	8.31	4.2	3.0	7.2
	5/4	377	47.12	38.17	8.95	23.74	14.9	4.1	19.0
	Total	14513	1672.76	1546.31	126.45	8.71	4.5	3.1	7.6
NO. 3BC	4/4	18562	1670.58	1622.28	48.30	2.60	3.7	+0.8	2.9
	5/4	552	50.23	42.58	7.65	13.86	14.1	1.1	15.2
	Total	19114	1720.81	1664.86	55.95	2.93	4.0	+0.7	3.3
Grand Total		111701	17633.09	16535.94	1097.15	9.82	4.2	2.0	6.2

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Table 1.—Continued

Lumber grade	Rough green Thickness	Volume	Potential value	Actual dry value	Value loss Total[a]	Per MBF[a]	Due to shrinkage	Due to[b] degrade	Total[a]
	Inches	*Fbm*			*Dollars*			*Percent*	
				WHITE OAK					
FAS	4/4	1595	478.50	431.46	47.04	29.49	3.8	6.0	9.8
	5/4	2768	844.24	740.64	103.60	37.43	4.3	8.0	12.3
	6/4	2076	664.32	622.88	41.44	19.96	3.2	3.0	6.2
	Total	6439	1987.06	1794.98	192.08	29.83	3.8	5.9	9.7
FAS WHND	4/4	297	57.92	56.48	1.44	4.85	2.4	0.1	2.5
FAS1F	4/4	1557	451.53	398.84	52.69	33.84	4.0	7.7	11.7
	5/4	2590	764.05	683.46	80.59	31.12	5.2	5.3	10.5
	6/4	2110	654.10	592.66	61.44	29.12	3.5	5.9	9.4
	Total	6257	1869.68	1674.96	194.72	31.12	4.3	6.1	10.4
SELECTS	4/4	560	156.80	143.31	13.49	24.09	2.7	5.9	8.6
	5/4	394	112.29	102.30	9.99	25.36	5.1	3.8	8.9
	6/4	364	109.20	100.84	8.36	22.97	4.7	3.0	7.7
	Total	1318	378.29	346.45	31.84	24.16	3.9	4.5	8.4
NO. 1C	4/4	10934	2186.80	1998.94	187.86	17.18	3.6	5.0	8.6
	5/4	9756	2048.76	1855.52	193.24	19.81	5.7	3.7	9.4
	6/4	3664	842.72	753.10	89.62	24.46	5.0	5.6	10.6
	Total	24354	5078.28	4607.56	470.72	19.33	4.7	4.6	9.3
NO. 1C WHND	4/4	2071	310.65	296.83	13.82	6.67	3.4	1.0	4.4
	5/4	464	76.56	70.88	5.68	12.24	5.4	2.0	7.4
	Total	2535	387.21	367.71	19.50	7.69	3.7	1.3	5.0
NO. 2C	4/4	13993	1749.12	1718.12	31.00	2.22	3.5	+1.7	1.8
	5/4	4852	655.02	602.02	53.00	10.92	8.7	+0.6	8.1
	6/4	527	73.78	70.00	3.78	7.17	6.1	+1.0	5.1
	Total	19372	2477.92	2390.14	87.78	4.53	4.9	+1.4	3.5
SW	4/4	5032	603.84	582.18	21.66	4.30	3.5	0.1	3.6
	5/4	1244	161.72	149.31	12.41	9.98	9.1	+1.4	7.7
	6/4	200	27.00	25.51	1.49	7.45	5.0	0.5	5.5
	Total	6476	792.56	757.00	35.56	5.49	4.6	+0.1	4.5
NO. 3AC	4/4	8551	983.36	926.26	57.10	6.68	4.0	1.8	5.8
	5/4	1051	131.38	106.85	24.53	23.34	15.4	3.3	18.7
	8/4	750	101.25	100.78	.47	.63	1.1	+0.6	0.5
	Total	10352	1215.99	1133.89	82.10	7.93	4.9	1.9	6.8
NO. 3BC	4/4	5551	499.59	494.18	5.41	.97	4.1	+3.0	1.1
	5/4	651	59.24	48.39	10.85	16.67	20.0	+1.7	18.3
	8/4	1298	120.71	124.81	+4.10	+3.16	1.8	+5.2	+3.4
	Total	7500	679.54	667.38	12.16	1.62	5.1	+3.3	1.8
Grand Total		84900	14924.45	13796.55	1127.90	13.29	4.6	3.0	7.6

[a] A plus (+) sign indicates that dry value of this grade and thickness class was greater than green value because of upgrade; therefore, the value loss must be positive.

[b] A plus (+) sign indicates that value loss due to shrinkage is greater than total value loss; therefore, value loss due to degrade must be positive.

Table 2.—Value loss during air-drying by species and lumber thickness

Rough green		Potential value	Actual dry value	Value loss				
Thickness	Volume			Total[a]	Per MBF[a]	Due to shrinkage	Due to[b] degrade	Total[a]
Inches	*Fbm*	— — — — *Dollars* — — — — —				— — — — *Percent* — — — —		
				BASSWOOD				
4/4	38199	6453.48	6067.93	385.55	10.09	4.5	1.5	6.0
5/4	491	69.35	61.56	7.79	15.87	9.8	1.4	11.2
6/4	1541	388.99	358.24	30.75	19.95	6.9	1.0	7.9
				RED MAPLE				
4/4	35411	5746.65	5538.85	207.80	5.87	2.6	1.0	3.6
5/4	9220	1675.47	1584.59	90.88	9.86	3.2	2.2	5.4
6/4	3654	909.39	874.76	34.63	9.48	2.6	1.2	3.8
8/4	3616	942.02	924.92	17.10	4.73	1.8	0.0	1.8
				YELLOW BIRCH				
4/4	34531	6534.18	6088.82	445.36	12.90	3.9	2.9	6.8
5/4	14349	3478.29	3292.97	185.32	12.92	3.4	1.9	5.3
6/4	2107	657.42	632.47	24.95	11.84	3.6	0.2	3.8
				SUGAR MAPLE				
4/4	25587	3961.65	3718.23	243.42	9.51	2.6	3.5	6.1
5/4	31502	6758.87	6195.41	563.46	17.89	3.6	4.7	8.3
8/4	7818	2084.38	1949.70	134.68	17.23	1.5	5.0	6.5
				YELLOW-POPLAR				
4/4	78488	12922.98	12139.07	783.91	9.99	3.5	2.6	6.1
6/4	8337	1768.03	1698.48	69.55	8.34	4.0	+0.1	3.9
				BLACK OAK				
4/4	29318	4411.78	4176.63	235.15	8.02	2.4	2.9	5.3
5/4	38337	9248.37	8767.52	480.85	12.54	3.2	2.0	5.2
				NORTHERN RED OAK				
4/4	100309	17698.39	16730.96	967.43	9.64	3.3	2.2	5.5
5/4	69683	18371.31	17037.29	1334.02	19.14	4.4	2.9	7.3
6/4	8014	2460.80	2313.04	147.76	18.44	4.4	1.6	6.0
				SCARLET OAK				
5/8	9145	1526.95	1442.47	84.48	9.24	4.6	0.9	5.5
4/4	37041	5085.73	4835.44	250.29	6.76	2.8	2.1	4.9
5/4	3354	893.99	829.22	64.77	19.31	2.4	4.8	7.2
				SCARLET, BLACK AND NORTHERN RED OAK				
5/8	9145	1526.95	1442.47	84.48	9.24	4.7	0.8	5.5
4/4	166668	27195.90	25743.03	1452.87	8.72	3.0	2.3	5.3
5/4	111374	28513.67	26634.03	1879.64	16.88	3.9	2.7	6.6
6/4	8014	2460.80	2313.04	147.76	18.44	4.4	1.6	6.0
				CHESTNUT OAK				
4/4	77624	10329.27	9726.32	602.95	7.77	4.1	1.7	5.8
5/4	12796	2441.15	2255.04	186.11	14.54	5.9	1.7	7.6
6/4	21281	4862.67	4554.58	308.09	14.48	3.6	2.7	6.3
				WHITE OAK				
4/4	50141	7478.11	7046.60	431.51	8.61	3.7	2.1	5.8
5/4	23770	4853.26	4359.37	493.89	20.78	7.1	3.1	10.2
6/4	8941	2371.12	2164.99	206.13	23.05	4.3	4.4	8.7
8/4	2048	221.96	225.59	+3.63	+1.77	4.3	+5.9	+1.6

[a] A plus (+) sign indicates that dry value of this species and thickness class was greater than green value because of upgrade; therefore, the value loss must be positive.

[b] A plus (+) sign indicates that value loss due to shrinkage is greater than total value loss; therefore, value loss due to degrade must be positive.

DISCUSSION

Previous research on the subject of seasoning degrade established unavoidable degrade losses for species groups in the Appalachian region *(Cuppett 1965)*. Although our method of determining value loss differed from that used in the earlier report, the percentages of value lost due to degrade are very similar. By separating species, lumber grades, and thicknesses, we have provided additional information.

Differences between potential value and air-dry value of hardwood lumber can be attributed to two basic factors: shrinkage, which is unavoidable, and degrade. If 1,000 board feet of lumber decreases 4 percent in lumber volume as a result of shrinkage during air-drying, the potential value is also reduced by 4 percent. Any additional reduction in potential value results from reductions in grade of boards. In tables 1 and 2, the percentage value loss has been separated into that due to shrinkage and that due to degrade. In some instances boards are upgraded during air-drying with a resulting increase in the board's value. This occurs because certain defects (shake, wetwood, stain) are more difficult to evaluate in the green lumber than they are in the dry; therefore, the area and severity of these defects may be overestimated. It is also possible for lumber to increase in grade during air-drying because of shrinkage. If a board shrinks to a lower surface measure, the total requirements for clear cutting units are reduced, and the board may qualify for a higher grade. Significant upgrading was demonstrated for some combinations of species, lumber grade, and board size. As a result, the value of some lumber classes increased during air-drying.

We have shown the dollar loss per thousand board feet for emphasis rather than for future comparison. This value changes whenever lumber prices change and is not as useful as percentage value loss. By using lumber prices from 1962, 1967, and 1973 it was possible to compare percentage value loss over time. For these three dates, percentage value losses differed by no more than 0.1 percent. Therefore, it is likely that the percentages will be applicable in the future whether lumber prices increase or decrease.

The value losses presented here are averages of several drying operations. Since we selected only mills that followed good sawing and drying practices, we believe that the figures represent a goal to strive for. They may be used as is if one desires to estimate the dry value of green lumber. For this purpose dry prices should be applied to green boards that were measured with a dry board rule. The resulting potential value must then be reduced by the appropriate value loss as demonstrated below:

Potential value of 1,000 board feet of green 4/4-inch No. 2 Common basswood	$100.00
No. 2 Common basswood	$100.00
Value loss from table 1 (percent)	3.6
Value loss (dollars)	$3.60
Estimated dry value	$96.40

The value loss figures may also be used for comparison to check drying performance. If a sawmill operator cannot achieve comparably low drying losses, he should find out why.

We stated that lumber shrinkage during air-drying was unavoidable. However, improperly sawn lumber may shrink from one thickness class to a lower thickness class. This can be avoided if the sawmill equipment is carefully maintained and if the green boards are thick enough to allow for shrinkage.

Value loss due to degrade can also be minimized by following recognized air-drying practices. Because lumber price per board foot increases with thickness, extra care should be taken in drying heavier stock.

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10 p. (USDA) Forest Serv. Res. Pap. NE-309)

Dry lumber prices were applied to green and air-dried lumber that was measured with a dry board rule. Values were summed by species, lumber grade, and thickness class. Differences between green and air-dried lumber value have been termed value losses and are given in dollars and in percentages. The percentages have been separated into loss due to shrinkage and loss due to degrade. Data for 10 hardwood species are included.

652.51--176.1--852.3--854:847.1

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Influence of Residual Stand Density on Regeneration of Northern Hardwoods

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NORTHEASTERN FOREST EXPERIMENT STATION
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MANUSCRIPT RECEIVED FOR PUBLICATION 11 APRIL 1974

SPECIES LIST

Common Name	*Latin Name*
American beech	*Fagus grandifolia* Ehrh.
Yellow birch	*Betula alleghaniensis* Britton
Sugar maple	*Acer saccharum* Marsh.
Red maple	*Acer rubrum* L.
Paper birch	*Betula papyrifera* Marsh.
White ash	*Fraxinus americana* L.
Red spruce	*Picea rubens* Sarg.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Balsam-fir	*Abies balsamea* (L.) Mill.
Pin cherry	*Prunus pensylvanica* L. f.
Striped maple	*Acer pensylvanicum* L.
Raspberry	*Rubus* spp.
American yew	*Taxus canadensis* Marsh.
Hobblebush	*Viburnum alnifolium* Marsh.

Influence of Residual Stand Density on Regeneration of Northern Hardwoods

by W. B. Leak
and D. S. Solomon

ABSTRACT

In a study of hardwood regeneration, experimental plots were treated to produce residual densities of 40, 60, 80, and 100 square feet of basal area per acre with 30, 45, and 60 percent sawtimber. After 9 years, numbers of stems and percent stocking were estimated for each species and they were rated for reproductive potential under different residual densities. Data from a 3-year-old patch cutting are given for comparison.

CONTROLLING stand density is probably the most common and most feasible method available to a forester for molding stand development. Residual stand density must be specified in a thinning operation since it affects growth per acre and the growth of individual crop trees. In prescribing shelterwood or selection cuttings, the effects of the residual stand on the amount and development of regeneration must be carefully considered. In scenic, recreational, and wildlife areas, more and more attention is being given to the control of understory development through manipulation of residual stand density and structure.

Past research with northern hardwoods in New England has provided guidelines for regeneration or understory development after clearcutting, patch cutting, and selection cutting (Leak and Wilson 1958; Marquis 1965; Marquis 1967). However, none of the published information on this subject specifies a range of residual densities and structures.

In 1963 and 1964 we began a study of the effects of residual stand density and stand structure (in terms of the percentage of sawtimber). Our main purpose was to determine the effects of residual stand conditions on tree and stand growth; these results will be reported separately. The effects of residual stand density and structure on understory development are described here.

METHODS

The study was established in second-growth northern hardwoods on the Bartlett Experimental Forest at Bartlett, N. H. These stands had originated after clearcutting 70 to 90 years before. Species composition was typical: primarily beech, red maple, and paper birch, together with some yellow birch and sugar maple and a few white ash and miscellaneous softwoods. The site apparently was not especially favorable for sugar maple, white ash, or the softwoods.

Forty-eight plots of ⅓ acre each were laid out. Each was surrounded by a 50-foot isolation strip, so that the plot proper plus its isolation strip occupied a little more than 1 acre.

Four levels of residual stand density were randomly assigned to these plots: 100, 80, 60, and 40 square feet of basal area per acre in trees 4.5 inches dbh and larger. Within each level of residual stand density, three residual stand structures were randomly assigned: 60, 45, and 30 percent sawtimber (trees 10.5 inches dbh and larger). Thus, the study comprised 12 combinations, each represented by four plots in a completely randomized design.

The plots were treated in the fall of 1963 by frilling and chemically treating the unwanted trees. Within the specifications of each treatment, the trees to be disposed of were chosen essentially at random. On a few plots, however, some effort was made to bring the species composition more in line with the average for the area (table 1). Trees that did not die were again treated in the spring of 1964. A few trees had to be cut before the 1965 growing season to complete the treatment. Treatment specifications were met almost exactly on both the ⅓-acre plots and the surrounding isolation strips.

In early summer of 1973, nine growing seasons after the main impact of the treatments, regeneration was sampled in eight 1-square-meter (10.8 sq. ft.) subplots on a diagonal across each ⅓-acre plot. For each subplot, all stems 2 mm (.04 inch) or larger in diameter at a point just above the root swell were recorded by species and diameter. For each plot, each treatment, and each species, the data were used to estimate the number of stems per hectare (2.47 acres)

Table 1.—Initial species composition of plots in percentage of basal area, by species, residual basal area, and percentage of sawtimber

Residual basal area	Sawtimber	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Red spruce	Eastern hemlock	Other
Sq. ft.						*Percent*				
100	30	7.6	4.6	3.4	46.1	23.0	1.2	.4	10.1	3.5
	45	36.4	13.7	1.0	22.8	17.8	0.0	.3	8.1	0.0
	60	21.7	9.4	11.1	34.4	14.7	2.0	.5	6.4	0.0
	All	21.8	9.2	5.2	34.5	18.5	1.1	.4	8.2	1.2
80	30	22.6	9.3	6.6	35.8	14.1	2.0	0.0	9.4	.3
	45	36.5	6.4	8.6	16.0	27.2	.9	1.1	3.2	0.0
	60	35.3	12.0	11.5	16.3	12.5	5.3	1.7	5.3	0.0
	All	31.5	9.2	8.9	22.6	18.0	2.7	1.0	6.0	.1
60	30	51.7	12.5	6.0	6.5	10.4	7.5	1.0	4.4	0.0
	45	37.6	11.1	3.7	21.3	19.0	.7	0.0	6.7	0.0
	60	14.7	3.8	5.5	37.7	28.9	0.0	0.0	9.4	0.0
	All	34.7	9.2	5.1	21.7	19.4	2.7	.4	6.8	0.0
40	30	28.0	10.0	0.0	32.2	23.8	.9	0.0	5.2	0.0
	45	24.5	3.4	3.6	26.4	21.5	7.6	0.0	13.0	0.0
	60	39.0	7.8	5.5	21.9	19.1	1.0	0.0	5.5	.3
	All	30.5	7.0	3.1	26.9	21.5	3.2	0.0	7.9	.1

and the percentage of subplots that contained at least one stem of that species (percent stocking). The summaries include only stems between 2 and 25 mm (.98 inch) in diameter since this size range covered the major differences in understory condition among treatments. Some of the stems tallied in 1973 were, of course, present before the treatment in 1963.

RESULTS

Percentage Stocking

On the average, stocking of the regeneration after 9 years was higher where the initial residual basal area was lower (table 2). Using the average stocking percentage of nine abundant species,[1] we found the effects of residual basal area to be significant. However, the response differed by species. Beech stocking —always high — increased slightly but consistently with lower residual basal area. Yellow birch stocking was less than 10 percent under 100 square feet and about doubled under lower residual densities. Sugar maple stocking varied little under all densities. Red maple stocking remained consistently high under the 60- to 100-square-foot densities, but increased markedly under 40 square feet. Paper birch responded somewhat to the 40-square-foot treatment. White ash stocking increased to some extent under 80-square-foot density or lower. Hemlock differed little. Stocking of pin cherry and *Rubus* increased slightly with lower stocking, but never became high. Striped maple reacted erratically to residual density. Hobblebush increased slightly with lower residual density. American yew also increased with lower density, especially at the 40-square-foot level.

Analysis of the average stocking for the nine species indicated that stocking was also related to some extent to percentage of sawtimber. There was a tendency toward higher stocking in plots with higher percentages of sawtimber; the probability of such differences occurring by chance was about 10 percent. These results confirm the practice of many foresters who feel that high shade (from large, tall trees) has less influence than low shade. However, the data in table 2 for individual species indicate that the relationship between percentage stocking and percentage of sawtimber is not consistent enough to support any conclusions.

Numbers of Stems

In most cases, numbers of stems per hectare followed much the same trends as percentage stocking (table 3); however, numbers probably give a more specific indication of regeneration ability than the presence or absence of a species, which determines percentage stocking. Table 3 also provides, for comparison, numbers of 3-year-old seedlings per hectare obtained on ⅔-acre plots by complete removal of everything down to 2 inches dbh (Marquis 1965). These patch cuts were made in second-growth stands on the Bartlett Experimental Forest very similar to those we used for this study. All the figures in table 3 are for undisturbed (not scarified) seedbeds.

Keeping in mind that there are more total stems per acre under the patch cuts, partly because the regeneration is younger, we can make some general observations about the effects of zero density compared to various other levels of residual density.

In comparison with any of the partial removals, patch cutting discouraged beech and red maple regeneration. Paper birch, and to a lesser extent yellow birch and sugar maple, was more abundant on the patch cuttings than under any of the residual densities. Ash responded somewhat better to the 40- and 80-square-foot residual densities than to patch cutting, although the species never became abundant. Pin cherry and *Rubus* were much more abundant on the patch cuts.

A somewhat more general picture of the effects of residual density is produced by combining commercial tree species into three recognized shade-tolerance groups: tolerant (beech, sugar maple, hemlock, red spruce, balsam-fir), intermediate (yellow birch, red maple, white ash), and intolerant (paper birch). Total numbers of stems per hectare

[1] Beech, yellow birch, sugar maple, red maple, paper birch, white ash, eastern hemlock, pin cherry, striped maple.

Table 2.—Average stocking of square meter plots by species, residual basal area, and percentage of sawtimber.

Residual basal area	Saw-timber	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Red spruce	Eastern hemlock	Balsam fir	Pin cherry	Striped maple	Rubus	Yew	Hobble-bush
Sq. ft.							*Percent*								
100	30	62.5	0.0	10.9	18.8	0.0	6.2	0.0	6.2	1.6	0.0	28.1	0.0	0.0	28.1
	45	71.9	15.6	3.1	43.8	15.6	9.4	3.1	3.1	0.0	21.9	6.2	6.2	0.0	0.0
	60	71.9	12.5	25.0	62.5	6.2	15.6	0.0	6.2	0.0	3.1	28.1	0.0	15.6	34.4
	All	68.8	9.4	13.0	41.7	7.3	10.4	1.0	5.2	0.5	8.3	20.8	2.1	5.2	20.8
80	30	75.0	12.5	9.4	34.4	3.1	6.2	3.1	3.1	0.0	9.4	40.6	0.0	3.1	21.9
	45	78.1	18.8	12.5	46.5	15.6	18.8	0.0	0.0	0.0	9.4	25.0	9.4	0.0	3.1
	60	79.7	21.9	23.4	60.9	10.9	32.8	0.0	9.4	0.0	14.1	51.6	3.1	0.0	39.1
	All	77.6	17.7	15.1	47.4	9.9	19.3	1.0	4.2	0.0	11.0	39.1	4.2	1.0	21.4
60	30	84.4	37.5	15.6	43.8	15.6	25.0	0.0	3.1	0.0	12.5	25.0	9.4	18.8	25.0
	45	87.5	18.8	12.5	34.4	6.2	3.1	0.0	9.4	0.0	18.8	21.9	9.4	0.0	21.9
	60	65.6	6.2	18.8	46.9	0.0	43.8	0.0	3.1	9.4	3.1	37.5	3.1	9.4	28.1
	All	79.2	20.8	15.6	41.7	7.3	24.0	0.0	5.2	3.1	11.5	28.1	7.3	9.4	25.0
40	30	90.6	21.9	6.2	81.2	18.8	9.4	0.0	0.0	0.0	12.5	40.6	9.4	0.0	12.5
	45	75.0	15.6	12.5	50.0	21.9	15.6	3.1	21.9	0.0	3.1	37.5	3.1	21.9	43.8
	60	81.2	25.0	21.9	59.4	12.5	46.9	0.0	3.1	0.0	21.9	53.1	12.5	28.1	28.1
	All	82.3	20.8	13.5	63.5	17.7	24.0	1.0	8.3	0.0	12.5	43.7	8.3	16.7	28.1

Table 3.—Numbers of stems (2 to 25 mm diameter) by species, residual basal area, and percentage of sawtimber

(In thousands of stems per hectare)

Residual basal area	Saw-timber	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Red spruce	Eastern hemlock	Balsam fir	Pin cherry	Striped maple	Rubus	Yew	Hobble-bush	Other	Total
Sq. ft.	*Percent*																
	30	15.0	0.0	1.4	5.6	0	.6	0.0	.3	.2	0.0	8.8	0.0	0.0	18.6	1.7	52.2
	45	35.0	5.3	.3	22.8	2.8	.9	0.0	0.0	0.0	8.8	.6	1.9	0.0	0.0	0.0	78.4
100	60	32.2	1.6	5.9	23.1	.6	6.2	0.0	.6	0.0	.6	3.1	0.0	19.4	44.4	1.4	139.1
	All	27.4	2.3	2.5	17.2	1.1	2.6	0.0	0.3	.1	3.1	4.2	.6	6.5	21.0	1.0	89.9
	30	50.9	4.1	1.2	7.8	1.2	2.2	.3	.6	0.0	2.5	9.1	0.0	3.1	20.9	.2	104.1
	45	37.5	14.7	9.4	14.7	3.4	4.4	0.0	0.0	0.0	2.2	4.7	6.9	0.0	4.4	.2	102.5
80	60	26.6	7.3	4.2	20.8	1.7	10.6	0.0	1.6	0.0	5.8	15.6	0.3	0.0	45.5	.3	140.3
	All	38.3	8.7	4.9	14.4	2.1	5.7	0.1	.7	0.0	3.5	9.8	2.4	1.0	23.6	.2	115.6
	30	57.2	20.3	9.4	16.2	4.1	12.2	0.0	.9	0.0	5.6	5.6	2.5	35.6	15.0	0.0	184.6
	45	57.2	5.3	1.9	11.6	.9	.3	0.0	2.8	0.0	4.4	5.9	.9	0.0	18.8	.3	110.3
60	60	38.4	3.1	4.7	26.9	0.0	11.2	0.0	.3	.9	.3	10.6	.3	19.1	23.8	3.8	143.4
	All	50.9	9.6	5.3	18.2	1.7	7.9	0.0	1.3	.3	3.4	7.4	1.2	18.2	19.2	1.4	146.1
	30	41.6	2.5	.9	87.2	3.4	2.2	0.0	0.0	0.0	12.2	15.3	5.6	0.0	25.6	0.0	196.5
	45	31.6	1.6	3.4	51.9	3.8	4.1	.3	2.8	0.0	.3	11.2	.3	54.1	45.3	2.4	213.1
40	60	37.5	11.9	6.6	49.7	6.6	18.8	0.0	.3	0.0	7.8	15.9	3.1	59.1	33.8	.2	251.3
	All	36.9	5.3	3.6	62.9	4.6	8.4	0.1	1.0	0.0	6.8	14.1	3.0	37.7	34.9	.9	220.3
0[a]	0	14.8	24.0	17.5	11.1	42.0	4.4				58.1	5.4	100.8			35.1	313.2

[a]Second-growth patches (Marquis 1965), 3-year regeneration, undisturbed seedbeds only.

were graphed over density level, combining all percentages of sawtimber (figure 1). Although total numbers of stems increase between 100 and 60 square feet residual density, the proportions of the tolerance groups are not greatly affected. At 40 square feet, there is a great increase in the intermediate group — almost entirely due to the increase in red maple. At zero square feet residual density, the numbers in each tolerance group are about equal.

Figure 1.—Average numbers of stems (in thousands per hectare) of commercial timber species by residual basal area and tolerance group: tolerant (beech, sugar maple, hemlock, red spruce, balsam-fir), intermediate (yellow birch, red maple, white ash), and intolerant (paper birch). Numbers under zero residual density based on 3-year-old patch cuttings *(Marquis 1965)*.

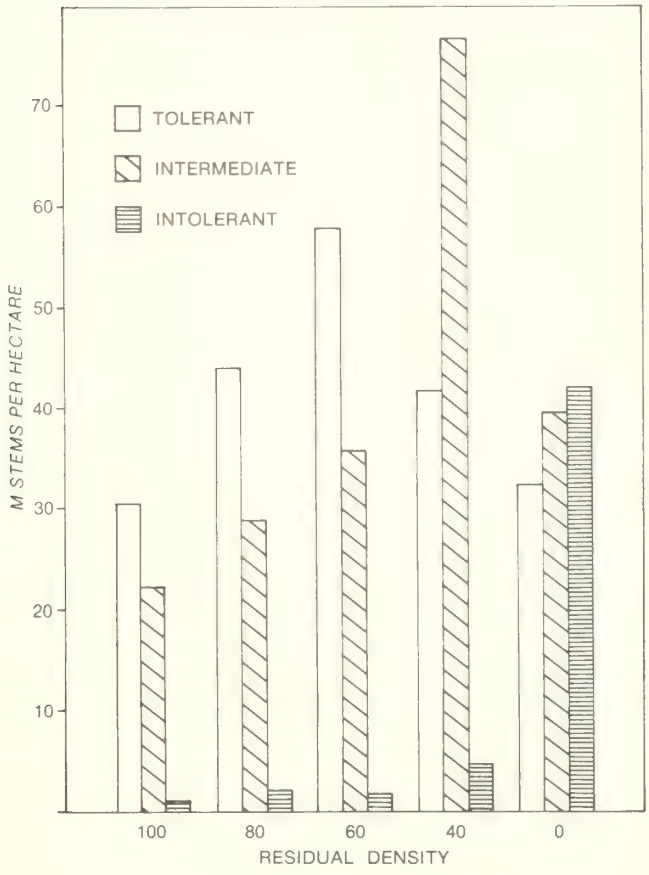
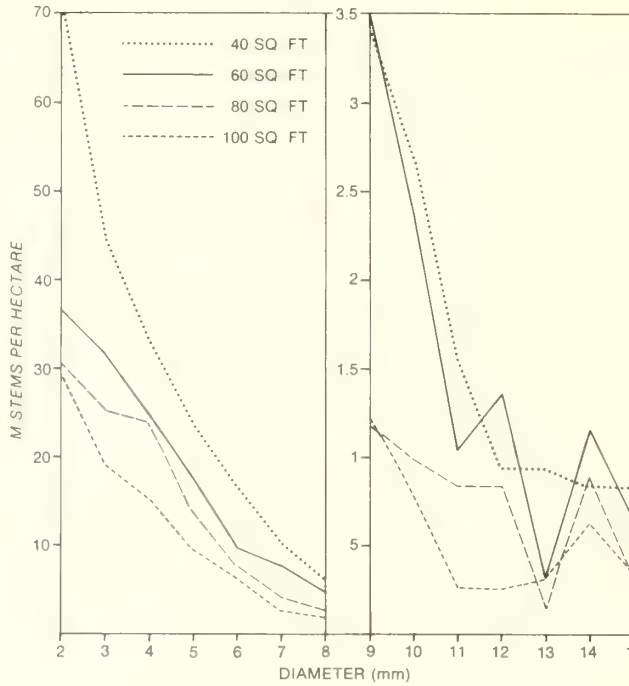


Figure 2.—Average numbers of understory stems per hectare (all species) over diameter class for four residual density levels.



Size

The understory on the low-density plots was noticeably thicker than on the higher-density ones. A summary of the size distribution of the understories indicates that the lower-density plots had increased numbers of stems up through the 12 to 13 mm diameter class. Beyond that point, the differences were not so distinct (figure 2).

CONCLUSION

The relative reproductive potentials of major species were rated as shown in table 4. Each rating is based on the number of stems per hectare (from table 3) expressed as a percentage of the total number of hardwood stems (ignoring shrubs and softwoods). If reproductive potential were ranked on the basis of numbers of stems *per se* — rather than percentage composition — the rankings would increase somewhat as the residual density became lower. Keep in mind that a more specific evaluation of response by species may

Table 4.—Reproductive potential of second-growth northern hardwood stands by species and residual density

Residual density	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Pin cherry	maple Striped
Sq. ft./acre								
100	VH	VL	VL	M	VL	VL	VL	VL
80	VH	L	VL	L	VL	VL	VL	L
60	VH	VL	VL	L	VL	VL	VL	VL
40	MH	VL	VL	VH	VL	VL	VL	L
0	VL	L	L	VL	M	VL	H	VL

Key: VH = Very high — 40–49 percent of hardwood stems
H = High — 30–39 percent of hardwood stems
M = Medium — 20–29 percent of hardwood stems
L = Low — 10–19 percent of hardwood stems
VL = Very low — 0– 9 percent of hardwood stems

be obtained by careful examination of the data in tables 2 and 3 on percentage stocking and numbers of stems.

Where the seedbed is scarified, intentionally or through logging, the rankings of paper and yellow birch will rise. However, even under these conditions, it is doubtful whether any of the partial removals would surpass zero residual density (patch cutting, not large-scale clearcutting) for these two species.

The rankings in table 4 will not apply very well to those sites that are unusually favorable for sugar maple, white ash, or softwoods. At present, such sites can best be detected by examining the vegetation already present.

In applying shelterwood, selection, or patch cutting to second-growth northern hardwoods, these ratings and the underlying basic data should be useful. They show how alternative residual densities will favor or discourage certain species. For recommendations for Allegheny hardwoods, with emphasis on black cherry, refer to the work by Marquis (1973).

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1975. Influence of residual stand density on regeneration of northern hardwoods. NE Forest Exp. Stn., Upper Darby, Pa.
7 p., illus. (USDA Forest Serv. Res. Pap. NE-310)

In a study of hardwood regeneration, experimental plots were treated to produce residual densities of 40, 60, 80, and 100 square feet of basal area per acre with 30, 45, and 60 percent sawtimber. After 9 years, numbers of stems and percent stocking were estimated for each species and they were rated for reproductive potential under different residual densities. Data from a 3-year-old patch cutting are given for comparison.

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Pendulum Impact Tests of Wooden and Steel Highway Guardrail Posts

by Charles J. Gatchell
and Jarvis D. Michie

USDA FOREST SERVICE RESEARCH PAPER NE-311
1974

NORTHEASTERN FOREST EXPERIMENT STATION
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MANUSCRIPT RECEIVED FOR PUBLICATION 30 MAY 1974

ABSTRACT

Impact strength characteristics of southern pine, red oak, and steel highway guardrail posts were evaluated in destructive impact testing with a 4,000-pound pendulum at the Southwest Research Institute. Effects were recorded with high-speed motion-picture equipment. Comparisons were based on reactions to the point of major post failure. Major comparisons of 6x6-inch and 6x8-inch red oak and southern pine posts with W6x8.5 and S3x5.7 steel posts showed wooden posts to be equal or superior to steel. The basis for wooden-post specifications should be the amount of knot-associated grain distortion in the middle third of the tension face of the posts. Acceptable posts are those with no single knot in the middle third of the tension face that disorients the grain for more than one-third the width of the face.

Pendulum Impact Tests of Wooden and Steel Highway Guardrail Posts

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GUARDRAIL POSTS

GUARDRAILS are important for protecting people on our highways. The design of a guardrail system—in which variables such as vehicle speed, weight, and angle of approach must be considered—represents a compromise of service requirements.

The relatively few full-scale crash tests made usually involve a 4,000-pound vehicle that is crashed into a barrier at an approach angle of 25 degrees and a speed of 60 miles per hour. Such a test costs several thousand dollars. Experience has shown that test results under one set of conditions should not be applied to other greatly different sets of conditions.

In the widely used semi-rigid strong-post guardrail system, the energy of a vehicle hitting it is transmitted to the earth by the posts supporting the flex or W-beam rail. Because the posts are the key to successful performance of a guardrail system, evaluating them without the high cost of full-scale crash-testing poses a challenge to researchers.

After a preliminary investigation (*Michie et al 1971*) the Forest Products Marketing Laboratory contracted with the Southwest Research Institute of San Antonio, Texas, to evaluate the dynamic performance of wooden and steel guardrail posts, using the technique of pendulum testing. A major objective was to determine if posts smaller in cross-section than the standard 8x8-inch wooden post would compare favorably with the W6x8.5 steel post. We found that 6x8 southern pine posts and 6x6 red oak posts showed generally superior characteristics.

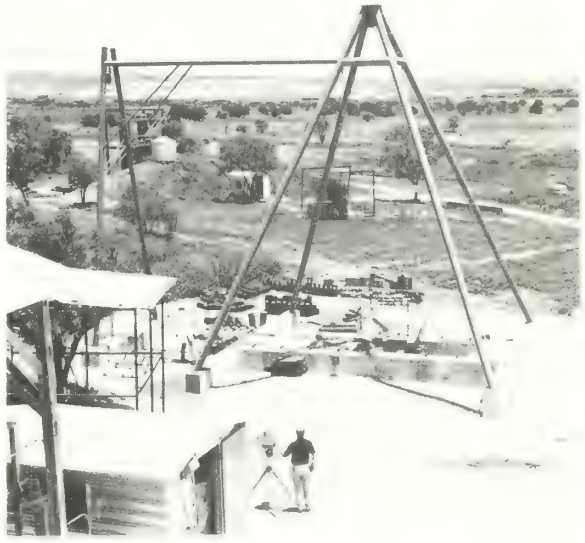
TESTING FACILITY

Pendulum

The Southwest Research Institute testing facility consisted of a pendulum, operating equipment, test-control and data-acquisition instrumentation, and high-speed motion-picture equipment (fig. 1). A 4,000-pound pendulum with an accelerometer mounted at the rear was suspended on a 26-foot swing radius in such a manner that it remained horizontal throughout the swing arc.

The posts were fixed at the lowest point of the pendulum arc, where the kinetic energy of

Figure 1.—The pendulum test facility.



the mass was greatest. For these tests, the impact velocity was slightly less than 20 miles per hour. This combination of mass and speed approximates the normal force component of a 4,000-pound vehicle hitting a guardrail at a speed of 60 miles per hour and an angle of 25 degrees.

The pendulum mass was a 3x6x1.5-foot block of reinforced concrete to the front face of which was attached an 8-inch diameter extra-heavy steel pipe filled with concrete for making contact with the post. A 1-inch thick pad of 70 durometer neoprene was attached to the surface of the steel bumper.

Post Holder

Because our objective was to evaluate the post rather than soil characteristics, the post holder (fig. 2) was designed to simulate frozen ground.

The front of the holder was an I-shaped member made of two 5-foot lengths of 6x8 steel box beam welded to a 1½-foot center section of 6x8 box beam. The ends of the 5-foot members were bolted to the concrete walls of the pendulum facility foundation.

The back of the post holder was a T made of 6x8 box beam. The crossbar top, welded to the upright, was positioned so its 6-inch face was across the 8-inch face of the upright (fig. 2). A slope was cut on the upper front face of the upright to prevent a sharp edge from affecting the reaction of the wooden posts to impact. A 2-inch pad of polyurethane was attached to the front of the crossbar.

For testing steel posts, the holder was modified to assure structural failure of the post above the clamp. The slope on the front face of the T was filled with a wooden block, and a metal brace was substituted for the polyurethane pad to minimize twisting of the steel post and to develop the maximum resistance about the strong axis of the post.

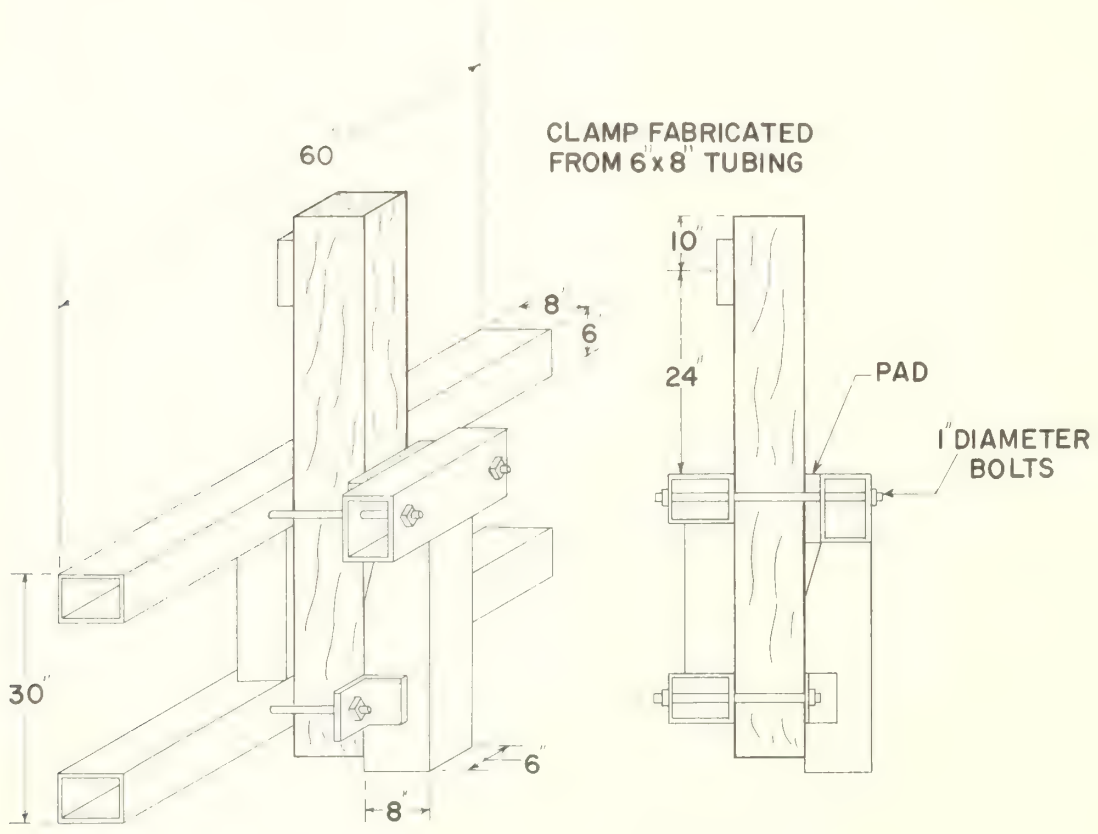


Figure 2.—Construction details of the post holder.

Preparation of Posts for Testing

To make identification of post failures easier, the top half of the front face of each wooden post was painted white. A 1-inch thick attenuation pad of 70 durometer neoprene was attached to each wooden post at the point of pendulum contact. An 8x8x12-inch wooden block was bolted to the front face of each steel post to act as an initial force attenuator and to insure overbending of the steel post so that it would not interfere with the pendulum mass on the backswing.

THE POSTS

Eight series of posts were tested:

Series	*Description*
RO 66	6x6-inch sound-square-edge boxed-heart red oak.
RO 68	6x8-inch sound-square-edge boxed-heart red oak.
SP 66	6x6-inch No. 1 SR boxed-heart southern yellow pine.
SP 68	6x8-inch No. 1 SR boxed-heart southern yellow pine.
SP 68$_c$	6x8-inch No. 1 dense SR boxed-heart creosote-treated southern yellow pine.
SP 86	6x8-inch No. 1 SR boxed-heart southern yellow pine (loading about the minor axis).
S3x5.7	S3x5.7 steel posts (standard AISC shape).
W6x8.5	W6x8.5 steel posts (standard AISC shape).

The steel posts were supplied by Southwest Research Institute from its own inventory. The red oak posts were purchased on the open market by the Forest Products Marketing Laboratory. The southern pine posts were contributed through the cooperation of the Southern Forest Products Association and Colfax Creosoting Company of Pineville, Louisiana.

All wooden posts were boxed-heart. Except for the creosote-treated southern pine pieces, all wooden posts were selected for evaluating potentially important characteristics. For example, in the untreated SP 68 series, posts A, B, and C had the pith centered and no knots in the middle third of each post; posts D and E had large knots in the center zone, and the pith was located just below the tension or compression face; post F had no knots in the middle third, but the pith was located near the surface of the piece; and post G had a centered pith and knots in the middle third. As far as possible, this pattern was followed with all other southern pine series.

Selection of red oak posts was limited to posts with or without knots in the central portion.

DATA GENERATION

Signals from an accelerometer, mounted at the rear of the pendulum mass, were continuously recorded throughout impact by a high-speed tape recorder operating at a speed of 60 inches per second. The tape was then played through an oscillograph, and tracings were recorded. Using Newton's second law of motion:

$$F = ma$$

the post resisting force (F) was determined from the pendulum mass (m) and its instantaneous deceleration (a). By applying the proper scales for force and time, the oscillograph tracings were converted to force-time curves.

The pendulum impact or initial velocity (V_o) was determined with signals from a crack-wire speed-trap. The peak resistance force and time of resistance to impact could be taken directly from the force-time curves. Other important parameters were calculated These were:

1. Final pendulum velocity—(V_f).
   The area under the force-time curve is linear impulse and is expressed by

$$\int_{t_o}^{t_f} F dt = m\,(V_f - V_o)$$

   where F is the resistance force acting on the pendulum mass, m is the pendulum mass, and V_o and V_f are the initial and final velocities. The impulse was measured by a planimeter, and the final velocity was calculated by

$$V_f = V_o - \frac{\text{Linear Impulse}}{m}$$

2. Fracture energy—(FE).
   The fracture energy is the change in kinetic energy resulting from impact. It was obtained from

$$FE = \tfrac{1}{2}\, m\, (V_f^2 - V_o^2)$$

3. Post displacement during impact—(d).
   The pendulum mass velocity was assumed to change linearly with time. Thus, the displacement of the post during contact with the pendulum was determined from

$$d \quad \left(\frac{V_f + V_o}{2}\right) \quad (t_f - t_o)$$

4. Average force during post displacement—(F_{avg}).
   The average force is an idealized constant force that acts through the distance of post displacement during impact. It was derived from dividing the fracture energy by the post displacement. Thus

$$F_{avg} = \frac{FE}{d}$$

METHOD OF ANALYSIS

The pendulum-impact test can be viewed in two ways. The first approach simulates a head-on crash of a 4,000-pound vehicle traveling at a speed of almost 20 miles per hour and hitting a single post in frozen ground. The total impulse and total time of post resistance are used in calculating the various post parameters. Results based on the total effects are available from the Northeastern Forest Experiment Station, Forest Products Marketing Laboratory, Princeton, West Virginia 24740.

In the second approach, used in this report, we considered the same test conditions to represent the normal force of a 4,000-pound vehicle hitting a barrier at a speed of 60 miles per hour and an approach angle of about 25 degrees. These conditions are normally used in full-scale crash tests of barrier systems.

In systems using strong wooden posts and steel-beam guardrail, wooden posts are rarely broken, and the energy is absorbed during deformation of the vehicle and soil. If a wooden post breaks, the tension in the rail transmits the impact to adjacent posts. During initial stages of impact, eight or more posts may be transmitting the load to the ground. For comparing post sizes and materials where a guardrail is used, analysis of force-time curves to the point of major failure is more precise than considerations of total effects.

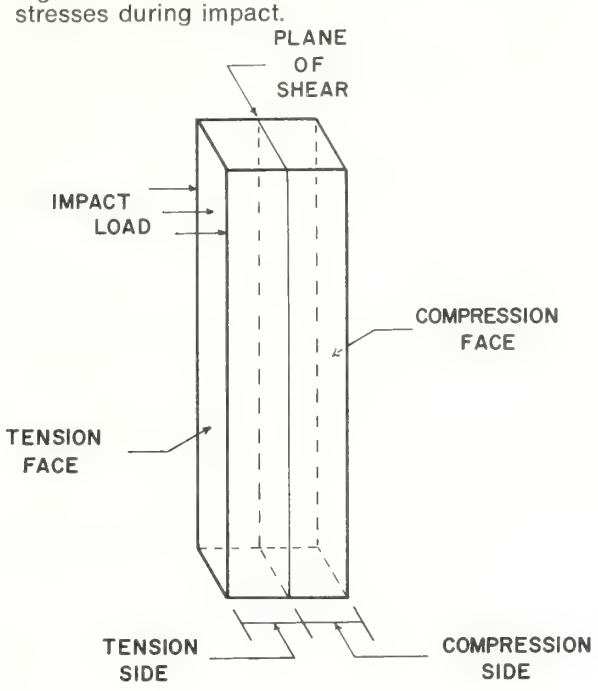
Beyond the point of major failure, it is difficult to compare wooden and steel posts, because wooden posts suffer a major material failure whereas steel posts suffer a major structural failure. Once the steel post fails initially, the subsequent displayed force is largely that used to bend the post around the top of the post holder.

The time of force generation is a factor in calculating such parameters as final pendulum velocity, fracture energy, and post displacement. Post displacement is used to calculate the average force acting on the post during impact. Once the major failure occurs, the rate of displacement of the post top increases. By terminating the analysis at the point of major failure, the precision of comparisons is increased.

The point of major failure can be pinpointed clearly by analysis of the high-speed motion-picture film in conjunction with the force-time curves. The movies were taken at either 580 or 880 frames per second. When the pendulum was swinging from left to right, the clamp could be observed on the film to move slightly downward and to the right. It remained in this position until visible failure occurred in the post, and/or a sharp decrease in the force-time curves was noted. Then it returned to its original position. By knowing the speed of the film and by counting the individual frames, we could locate the point of major failure on the force-time curves with no greater than 1 msec (millisecond) error for the slower speed film (580 frames per second) and 0.5 msec error for the higher speed film (880 frames per second).

In bending, wood is subjected to three types of basic stress: tension, compression, and shear. In a guardrail post, the face receiving the impact is in tension and the opposite face is in compression (fig. 3). Where shear is

Figure 3. — Location of stresses during impact.



likely (as with oak), it will generally occur in a plane parallel to the tension face and at or near the center of the post.

Since posts usually are inserted in the ground to a depth equal to about half their length, the greatest forces can be expected to occur in the middle third of the post. When the ground is frozen, the post acts as a cantilever beam, and the major stress will occur at the ground line or middle of the post. When the ground is very soft, the post is free to pivot and post properties are not significant.

In between these extremes are found the conditions of "normal" use. The top of the post moves in the direction of the applied force. As the post moves, the soil at the ground line is compressed and offers increased resistance to the middle third of the post. If we assume adequate resistance of the soil, the bottom of the post is essentially restrained from movement and the maximum tensile stresses will occur in the middle third of the post.

Examples of force-time curves and failure sequences are given in figures 4, 5, and 6. The first force peak in each wooden post curve represents an acceleration of the post to the speed of the pendulum. It is unlikely that any damage to the wooden post occurs here. Once the post and pendulum are moving at the same speed, the accelerometer on the pendulum records no resistance, and the force curve falls toward zero.

As the wooden post bends, it stiffens; and the second peak occurs. During this period, the clamp is moving downward and to the right. At about the time of peak resistance, a major failure occurs in the wooden post. The curve then drops abruptly to zero. Examination of the broken posts in conjunction with force-time curve and high-speed motion-picture film analysis provided an evaluation of strength-reducing defects.

RESULTS

General

In these dynamic tests, the shape of the force-time curve is a result of impact velocity. As long as the tests are dynamic, the impulse or area under the curve should remain the same. At lower impact speeds, we would expect smaller peak forces and longer periods of resistance, the fracture energy remaining about the same. Rather than being absolute, the force-time curves and calculated impact values should be considered indexes of behavior that are useful for making comparisons.

The strength properties of a wooden post depend primarily upon density and location of defects, especially knots. Within a species, speed of application of load and location of defects are of great importance. Dynamic loading can produce strength values that are two or three times those of static tests. It is the dynamic values from impact loads that we are concerned with when discussing guardrail posts.

Almost all the strength properties of wood increase significantly as wood dries below the fiber saturation point of about 30 percent moisture content. However, in posts of guardrail size, this normal increase in strength may not occur because of the development of checks around knots and in the area near the shear plane. Drying checks have little, if any, effect on strength in tension, and only a slight negative effect on strength in compression.

In sound posts, knots are the single most

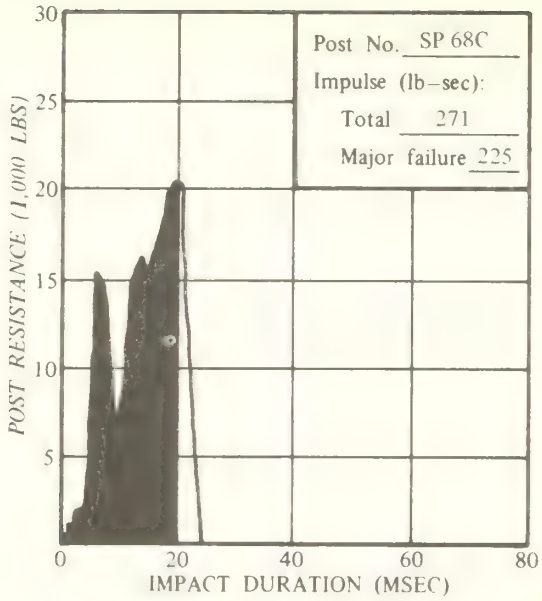
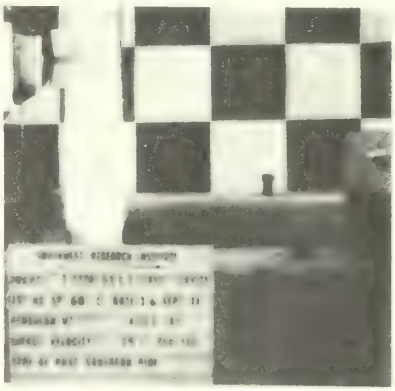
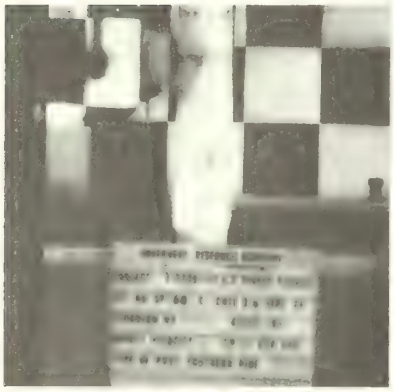


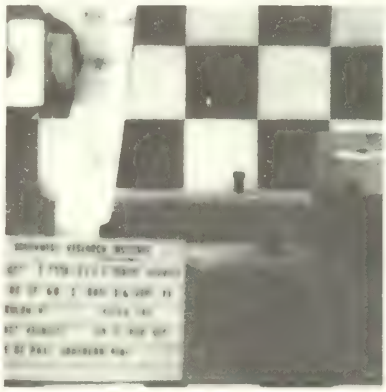
Figure 4.—Force-time curve and failure sequence for southern pine post SP 68C (1 msec = 0.001 second).



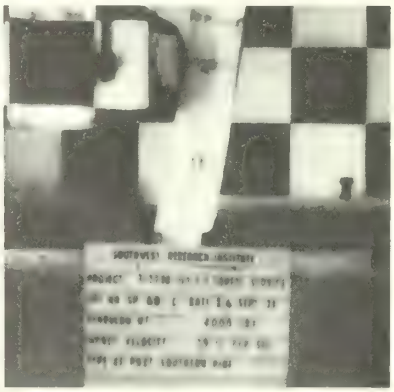
T = 0 msec



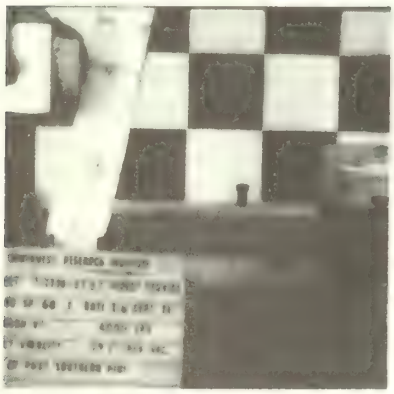
T = 6 msec



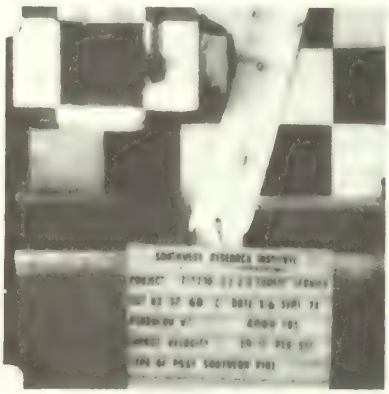
T = 15 msec



T = 16 msec



T = 17 msec



T = 19 msec

T = 28 msec

At T = 0 msec, the pendulum contacts the attenuation pad. At T = 6 msec, the pendulum has compressed the pad and has met with post resistance, thus forming the first peak in the forcetime curve. The pendulum and the post move at the same velocity and, as there is no post resistance, the curve drops down. At T = 15 msec, the post is offering resistance, but there is no visible damage. At T = 16 msec, failure at the clamp on the tension side begins and continues across the cross-section through T = 17 msec until complete at T = 19 msec. At T = 28 msec, failure is clearly shown and, from the point of major failure at T = 19 msec, the post top has sprung ahead of the pendulum.

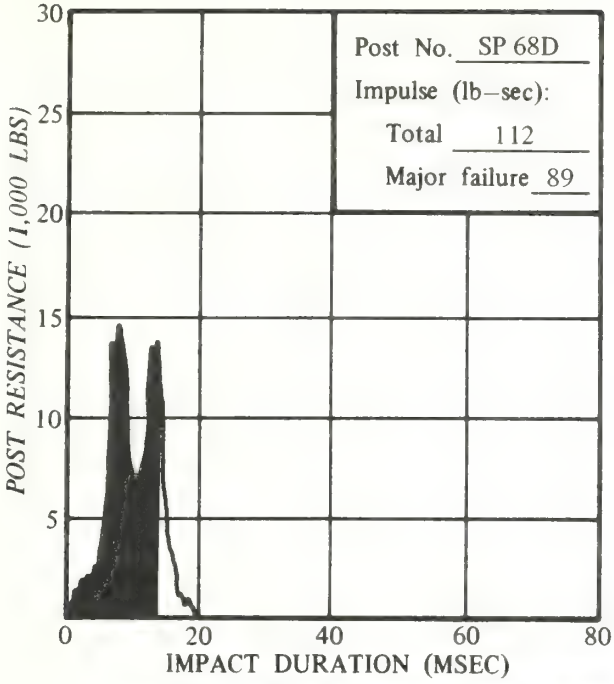
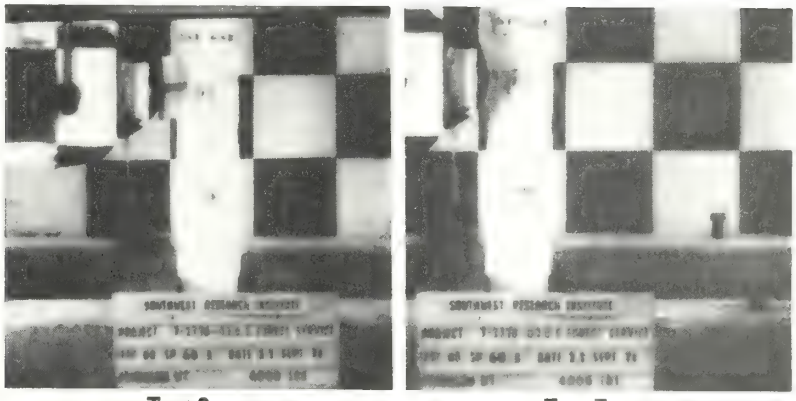
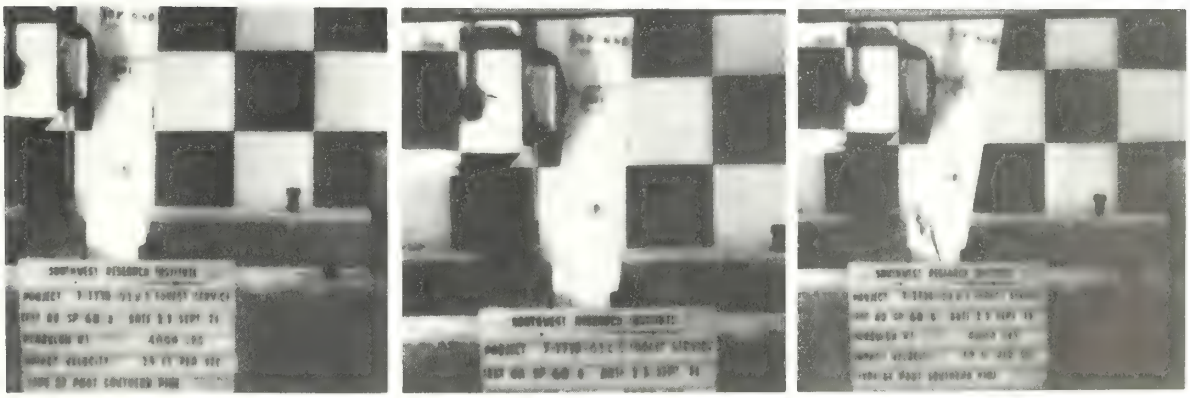


Figure 5.—SP 68D force-time curve and failure sequence for southern pine post SP 68D (1 msec = 0.001 second).



T = 0 msec T = 7 msec



T = 12 msec T = 14 msec T = 19 msec

As in figure 3, T = 0 msec and T = 7 msec show the compression of the attenuation pad and the generation of the first peak force. At T = 12 msec, the post is again offering resistance. At T = 14 msec, drastic post failure begins, owing to severe knot-caused grain distortion on the tension face. By T = 15 msec, the major failure, as clearly shown at T = 19 msec, is about complete.

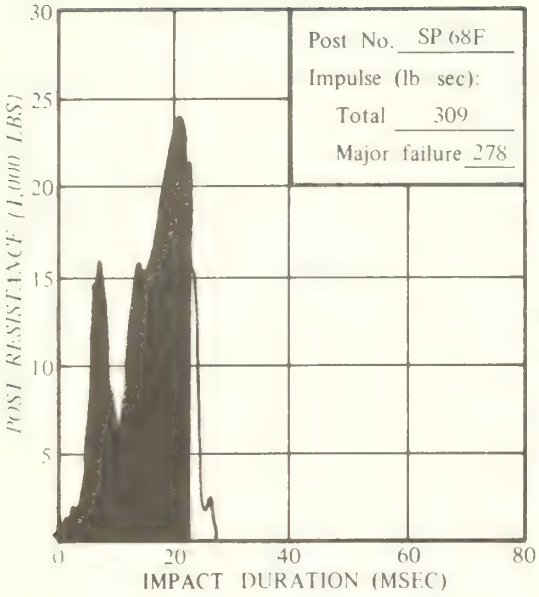
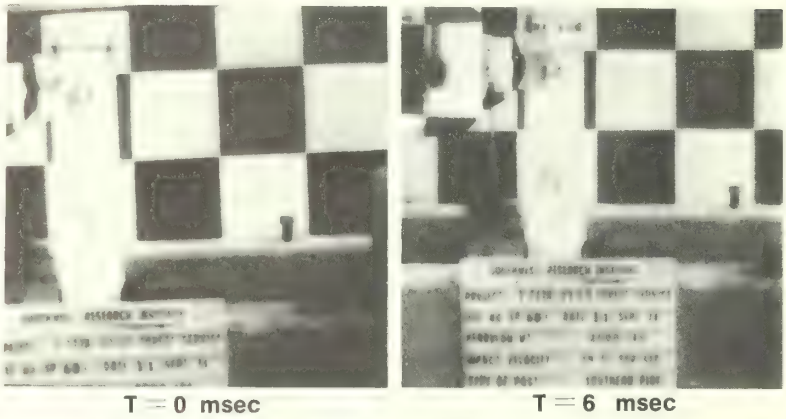
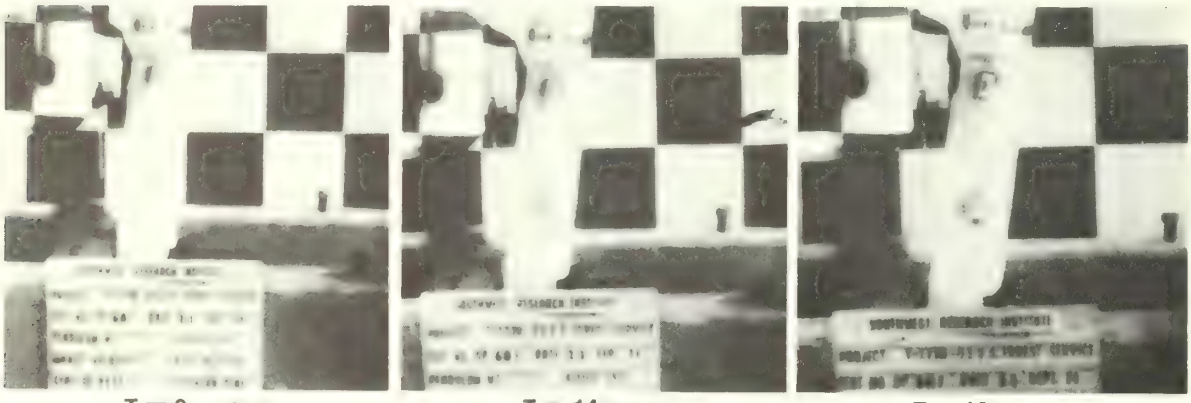


Figure 6.—Force-time curve and failure sequence for southern pine post SP 68F (1 msec = 0.001 second).

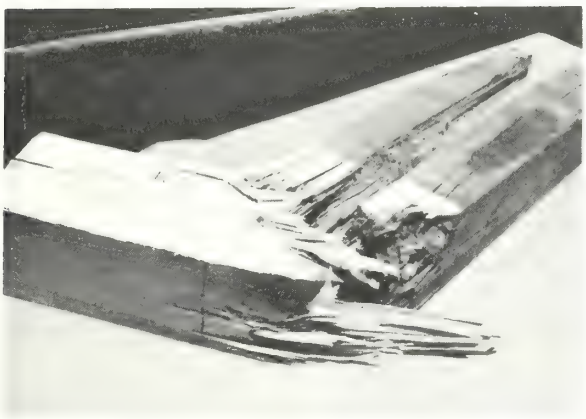




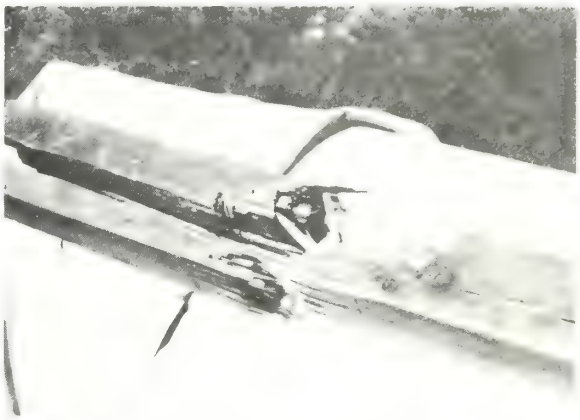
As in figure 3, T = 0 msec and T = 6 msec show the compression of the attenuation pad and the generation of the initial peak force. At T = 9, 14, and 16 msec, the post is bent, with no visible damage. At T = 17 msec, failure begins as a crack appears on the front face between the two letter "F's". At T = 20 msec, major failure on the tension face and across the cross-section is visible. Also, shear has occurred. At T = 24 msec there is no post resistance and shear is apparent.

Figure 7.—Examples of knot influence on post reaction to impact. Note: all failures occurred in the middle third of the post.

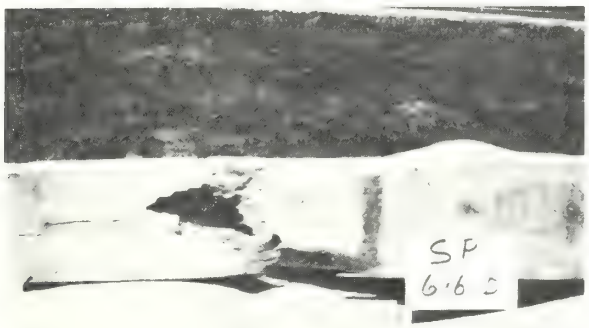
Non-Critical Knots



RO 68B. A 2-inch knot on corner of front and tension faces was located 2 inches below the clamp. Grain distortion extended across one-fourth the width of the tension face. Post impact strength: above average for the RO 68 series.

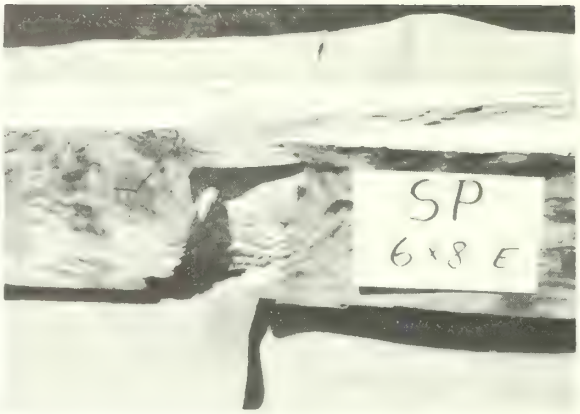


RO 68G. Two small knots (½ and 1 inch) in the middle of the back face were located 2 inches above the clamp. Post impact strength: above average for the RO 68 series.



SP 66D. Failure occurred at the clamp midway between knots clusters on the tension face. No single knot disoriented the grain for more than one-third the width of the tension face. Post impact strength: average for the SP 66 series.

SP 68G. Three knots were located 4 to 6 inches above the clamp on the tension face. No knot disoriented the grain for more than one-third the width of the tension face. Post impact strength: above average for the SP 68 series.



SP 68E (two views, above): a 1½-inch knot located about 11 inches above the clamp on the tension face disoriented the grain across the entire 6-inch width of the face. Other knots from the same cluster on front and compression faces had no effect on strength. Post impact strength: far below average for the SP 68 series.

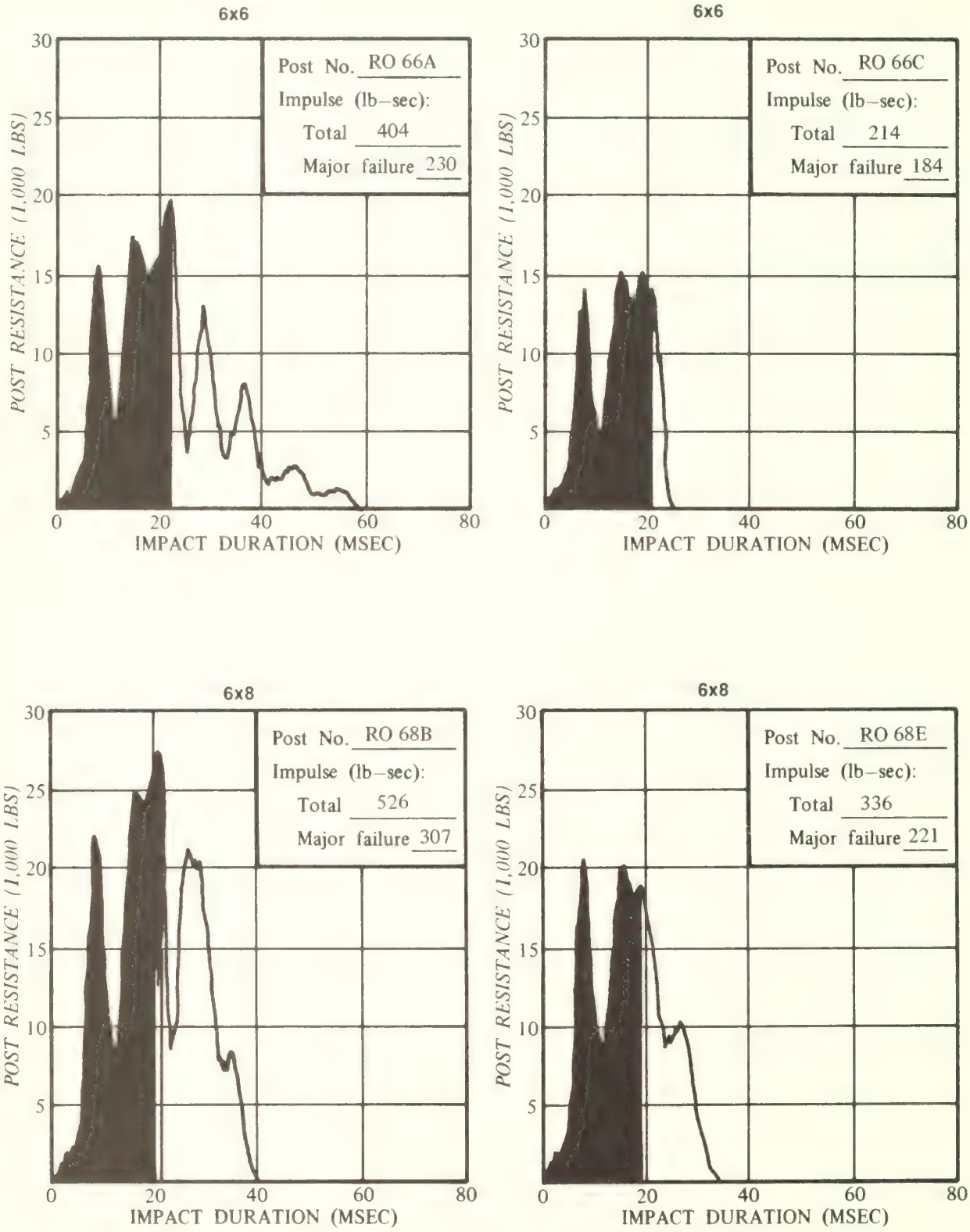
RO 68E (two views, below): a 3-inch knot located 3 inches above the clamp on the edge of the front and tension faces disoriented the grain for about one-half the width of the tension face. Post impact strength: weakest of the RO 68 series.

Table 1.—Red oak post pendulum-impact values to the point of major failure

Post No.	Area of post cross-section	Aver.[a] rings/inch	Specific[a] gravity	Moisture content at test	Pendulum velocity		Elapsed[c] time	Impulse	Fracture energy	Aver. force	Displacement	Peak force
					Impact	Final						
	Sq. in.	*No.*	*ODW/ODV*[b]	*Pct.*	*Ft./sec.*	*Ft./sec.*	*Msec*	*lb-sec*	*Ft-Kips*	*Kips*	*In.*	*Kips*
RO 66E	36.0	12	0.69	48	29.0	26.9	20	269	7.36	13.1	6.7	18.2
RO 66A	34.0	14	.74	73	25.0	23.2	19	230	5.53	12.1	5.5	19.5
RO 66B	36.6	7	.74	46	26.3	24.7	18	191	4.87	10.6	5.5	18.0
RO 66C	36.6	8	.67	52	25.4	23.9	18	184	4.53	9.2	5.9	15.5
RO 66DD	38.4	8	.73	41	25.7	24.3	18	174	4.34	9.7	5.4	16.7
Average	36.3	—	0.71	52	26.3	24.6	19	210	5.33	11.0	5.8	17.6
RO 68C	48.6	8	0.65	48	26.1	23.5	19	314	7.81	16.5	5.7	26.3
RO 68G	50.8	7	.64	57	26.0	23.6	20	302	7.48	15.1	6.0	24.0
RO 68B	52.9	7	.72	51	25.5	23.1	19	307	7.45	16.2	5.5	27.5
RO 68D	48.6	12	.66	57	26.4	24.3	19	271	6.86	14.3	5.8	24.5
RO 68A	51.5	6	.67	54	26.3	24.5	17	231	5.86	13.6	5.2	22.3
RO 68E	48.0	6	.63	73	25.7	24.0	16	221	5.49	13.8	4.9	20.7
Average	50.1	—	0.66	57	26.0	23.8	18	274	6.82	14.9	5.5	24.2

[a] Values determined from sample taken along a representative radius starting 1 inch from the pith.
[b] Oven-dry weight/oven-dry volume.
[c] 3 msecs subtracted from total time as shown on force-time curves to allow for compression of attenuation pad.

Figure 8.—Examples of force-time curves for red oak 6x6-inch and 6x8-inch posts (1 msec = 0.001 second). Shaded area is the impulse to major failure.



important defect affecting their performance as guardrail support. The specific location of knots within the post and the extent to which the grain is distorted around knots located at or near the point of greatest tensile stress can have a serious effect on strength. The effect of knots on compressive and shear strength is small.

Examples of critical and non-critical knots are shown in figure 7. None of the non-critical knots distorted the grain for more than one-third the width of the tension face. Those knots causing a reduction in strength distorted the grain for one-half or more the width of the tension face.

Red Oak

The impact data for the red oak 6x6 and 6x8 series are given in table 1. In all cases, the peak force was reached at or immediately before the point of major failure. For both groups, the elapsed time to peak force was about 18 msecs after the attenuation pad on the post had been compressed (about 3 msecs). The average peak force for the 6x6 posts was 17.6 Kips (kilopounds) and for the 6x8 posts was 24.2 Kips.

Eight of the 11 oak posts suffered shear failure either above or below the top of the clamp. There was no apparent relationship between impact values and whether or not there was shear failure. Also, whether the shear failure occurred above or below the clamp was unimportant. In the 6x6 group, for example, post RO 66E (the strongest) and post RO 66DD (the weakest) did not have shear failure. In the 6x8 group, RO 68C (the strongest) and RO 68A (second weakest) had shear failure above the clamp. Posts RO 68B, D, and G had shear failure below.

Examples of characteristic force-time curves for the red oak series are given in figure 8. Posts RO 66A and RO 68B had no strength-reducing defects. Each was about the strongest in its series. Post resistance increased until shear failure occurred. The unshaded area to the right of major failure represented the energy required to break the tension and compression sides following shear.

The force-time curves for RO 66C and RO 68E reflect the influence of strength-reducing knots. The reaction to impact of RO 66C was similar to that of RO 66A until 19 msecs had elapsed. At that point, RO 66C failed in tension at the clamp, and shear (major failure) above the clamp followed. The tension failure was affected by knot-associated grain distortion that covered more than one-third the width of the tension face. An additional knot cluster located 6 inches above the clamp on the front and compression faces caused the immediate failure of the compression side. After shearing, the compression side above the clamp can be viewed as a smaller post with knots on its tension face. Because of the knot cluster, there was no residual strength after the point of major failure.

The failure of RO 68E was affected by a 3-inch knot located about 3 inches above the clamp. The knot-associated grain distortion covered more than one-half the width of the tension and front faces. Failure started on the tension face and proceeded across the post's cross-section. Shear did not occur.

Southern Pine

The impact data for the southern pine series are given in table 2. In the untreated No. 1 SR series (SP 66, SP 86, and SP 68), failure was generally brashy to somewhat fibrous. Once begun, failure generally extended across the cross-section, without shear. The creosote-treated No. 1 Dense SR posts (SP 68$_c$) suffered more fibrous breaks, laminar failures at summerwood-springwood interfaces, and considerably less failure on the compression side. The greater resistance to impact of the treated posts was attributed mainly to the higher average percentage of summerwood per annual ring.

In the untreated series, strength values show the trends related to moments of inertia that were reported earlier (*Michie et al. 1971*). The SP 66 series was weakest of all. The SP 8x6 posts contained the same amount of wood as the SP 6x8 posts but were loaded about the minor axis. The SP 86 values fell between the SP 66 and SP 68 values.

Typical examples of force-time curves for the SP 66, SP 68, and SP 68$_c$ (creosote-treated) series are given in figure 9. The southern pine curves are characteristically different from the red oak curves because of the

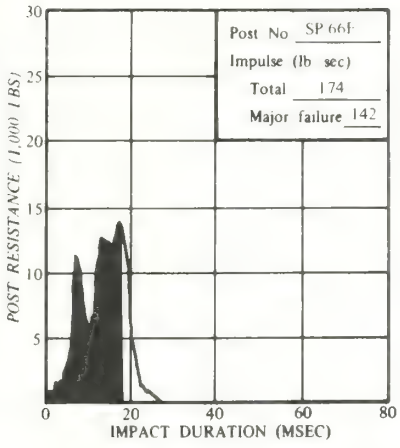
Table 2.—Southern pine pendulum-impact values to the point of major failure

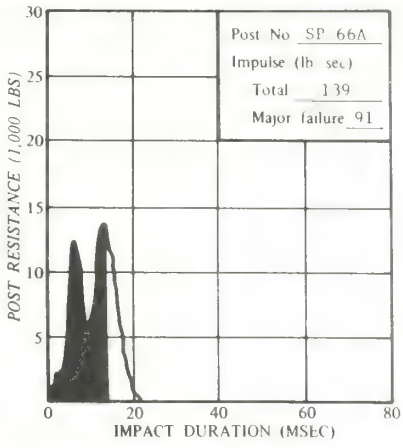
Post No.	Area of post cross-section	Aver.[a] rings/inch	Percent[a] summerwood	Specific[a] gravity	Moisture content at test	Pendulum velocity		Elapsed time[c]	Impulse	Fracture energy	Aver. force	Displacement	Peak force
						Impact	Final						
	Sq. in.	*No.*	*Pct.*	*ODW/ODV*[b]	*Pct.*	*Ft./sec.*	*Ft./sec.*	*Msec*	*Lb-sec*	*Ft-Kips*	*Kips*	*In.*	*Kips*
SP 66C	35.4	5	28	0.58	22	26.1	24.8	18	168	4.27	9.3	5.5	14.5
SP 66F	35.4	5	30	.61	30	25.9	24.7	14	142	3.58	10.1	4.3	14.2
SP 66H	36.6	5	26	.49	23	26.3	25.3	16	127	3.27	7.9	5.0	13.7
SP 66D	35.4	8	31	.57	22	26.0	25.2	11	97	2.42	8.9	3.3	14.7
SP 66A	34.8	10	34	.59	22	26.7	26.0	10	91	2.39	9.1	3.2	13.7
SP 66B	36.0	5	17	.45	22	25.8	25.1	11	88	2.24	8.0	3.4	14.5
SP 66G	36.0	6	21	.45	20	25.7	25.1	9	69	1.76	7.7	2.8	12.5
Average	35.7	—	27	0.53	23	26.1	25.2	13	112	2.85	8.7	3.9	14.0
SP 86A	47.2	7	31	0.56	28	25.5	23.8	17	211	5.20	12.4	5.0	22.2
SP 86F	47.2	9	32	.55	20	28.9	27.4	15	175	4.93	11.7	5.1	19.7
SP 86C	47.8	9	33	.54	24	28.4	27.1	14	164	4.55	11.7	4.7	17.5
SP 86G	47.2	8	29	.55	22	28.7	27.5	14	146	4.12	10.4	4.7	16.5
SP 86B	48.0	7	28	.51	22	28.9	27.8	14	139	3.94	9.9	4.8	15.5
SP 86E	47.2	4	40	.56	28	29.2	28.4	11	105	3.04	9.6	3.8	16.5
SP 86D	48.0	4	21	.47	51	28.5	27.7	10	105	2.98	10.6	3.4	15.5
Average	47.5	—	31	0.53	28	28.3	27.1	14	149	4.11	10.9	4.5	17.6
SP 68F	48.0	7	29	0.61	23	28.4	26.1	20	278	7.58	13.9	6.5	24.0
SP 68A	46.6	8	35	.53	23	29.2	27.0	21	270	7.57	12.8	7.1	23.0
SP 68G	48.0	7	30	.52	29	27.1	25.1	21	250	6.51	11.9	6.6	19.8
SP 68B	47.2	6	43	.59	24	27.2	25.2	17	248	6.51	14.6	5.4	22.4
SP 68C	48.0	7	27	.50	25	28.8	26.9	18	225	6.26	12.5	6.0	20.9
SP 68E	48.6	5	24	.45	21	26.0	25.2	10	94	2.42	9.5	3.1	14.5
SP 68D	48.6	4	25	.49	21	28.3	27.6	11	89	2.50	8.1	3.7	14.5
Average	47.9	—	30	0.53	24	27.9	26.2	17	207	5.62	11.9	5.5	19.9
SP 68E$_c$	48.8	11	46	0.57	—	25.8	22.0	34	476	11.36	14.0	9.7	23.7
SP 68C$_c$	48.0	15	48	.60	—	25.8	23.4	27	431	10.39	16.0	7.8	24.5
SP 68G$_c$	47.4	4	44	.52	—	29.1	26.9	21	266	7.44	12.7	7.1	17.5
SP 68F$_c$	48.8	5	32	.46	—	26.4	24.3	20	263	6.68	13.2	6.1	18.7
SP 68A$_c$	48.2	7	39	.52	—	25.6	23.5	17	252	6.19	14.8	5.0	22.0
SP 68D$_c$	47.4	6	36	.49	—	26.3	24.3	19	238	6.03	12.5	5.8	16.9
SP 68B$_c$	47.4	7	36	.55	—	26.0	24.2	17	229	5.74	13.4	5.1	19.5
Average	48.0	—	40	0.53	—	26.4	24.1	22	308	7.69	13.8	6.7	20.4

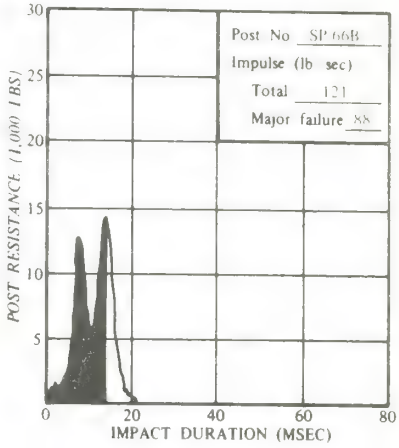
[a] Values determined from sample taken along a representative radius starting 1 inch from the pith.
[b] Oven-dry weight/oven-dry volume.
[c] 3 msecs subtracted from total time as shown on force-time curves to allow for compression of attenuation pad.

Figure 9.—Examples of force-time curves for southern pine untreated No. 1 SR 6x6 and 6x8 posts and No. 1 dense creosote-treated 6x8 posts.

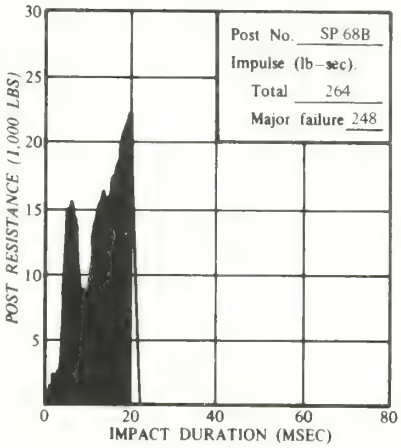
Untreated No. 1 SR southern pine 6x6-inch posts.

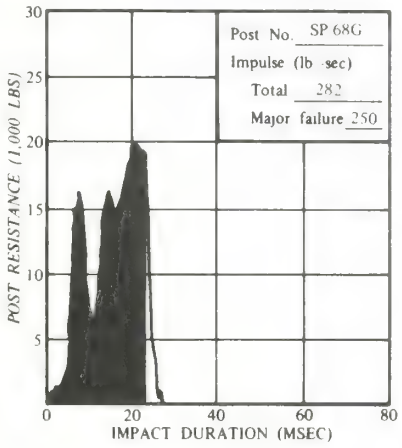


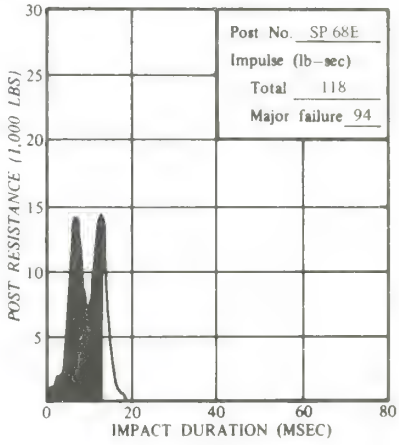




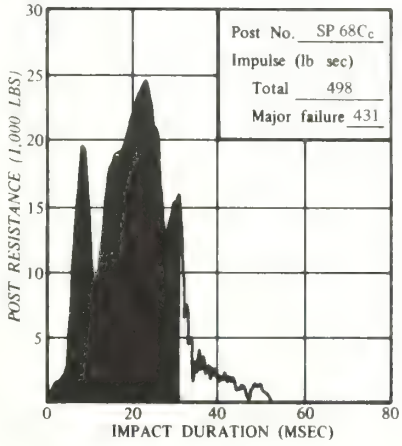
Untreated No. 1 SR southern pine 6x8-inch posts.

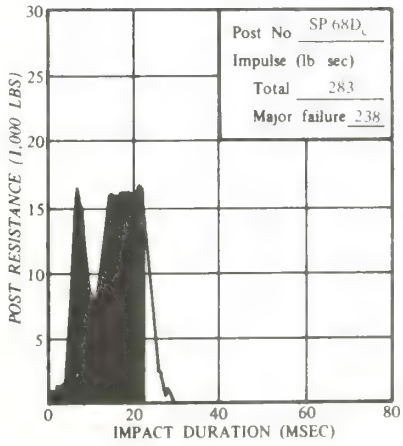






Creosote-treated No. 1 dense SR southern pine 6x8-inch posts.





general absence of shear failure in the southern pine posts. Once major failure occurred across the cross-section, there was nothing left to offer resistance to the pendulum.

The SP 66F curve was typical of the stronger posts in the 66 series. For these posts (SP 66 C, F and H), there were no knots on the tension face in the middle third of the post, and failure was somewhat fibrous.

The influence of knot-associated grain distortion on strength is shown by a comparison of the curves of SP 66A and B. SP 66B had no knots influencing its failure. The low resistance to impact was attributed to the low percentage of summerwood (17 percent) and low specific gravity (0.45). SP 66A, with twice as much summerwood (34 percent) and a 25-percent greater specific gravity (0.59), performed in all respects the same as SP 66B. In the middle third of the tension face of SP 66A, there was a large knot that disoriented the grain for more than one-third the width of the face.

The influence of the amount of knot-associated grain distortion was most dramatically shown in the untreated SP 68 series. The force-time curve for SP 68G was about identical to that for the other strong posts in the series (SP 68A, B, C, and F), which had no knots in the middle third of the posts. SP 68G was average in percentage of summerwood and specific gravity. It had three knots located 4 to 6 inches above the clamp on the tension face (fig. 7). Though the total area covered by the knots was about three-fourths the width of the tension face, no single knot distorted the grain for more than one-third the width of the face. The main line of failure was in clear wood across the cross-section at the top of the clamp.

Posts 68E and D, though slightly low in percentage of summerwood and specific gravity, performed poorly because of knot-associated grain distortion. SP 68E (fig. 7) had a 1½-inch knot about 11 inches above the clamp that disoriented the grain across the entire 6-inch width of the tension face. Failure beginning immediately below this knot was clearly visible in the high-speed motion pictures. Other knots from the same cluster on the other faces had no effect.

Post SP 68D had the opposite knot configuration. Two 2-inch knots in the center and right edge of the tension face disoriented the grain for about one-half the width of the tension face. Failure of SP 68D, which began on the tension face, was unaffected by a single knot on the compression face that disoriented the grain for the entire 6-inch face width.

In the creosote-treated series (SP 68$_c$), SP 68D$_c$ was the only post affected by knot-associated grain distortion. A 1-inch knot located 10 inches above the clamp distorted the grain for about one-half the width of the tension face. Failure began immediately below the knot.

SP 68C$_c$ exhibited superior properties. Part of this excellent performance was attributed to high percentage of summerwood (almost 50 percent) and specific gravity (0.60). The manner of failure was also a factor. About the time that the peak resistance occurred, laminar failures occurred, beginning just below the tension face and moving toward the center of the post. These successive failures at the summerwood-springwood interfaces resulted in an extension of time to the point of major failure and increased the total resistance to impact.

Steel Posts

Data for the weak (S3x5.7) and strong (W6x8.5) steel posts are given in table 3 and figure 10. The post holder was modified for these posts to insure structural failure above the clamp. The slope on the front face of the T-brace was filled with a wooden block and a U-shaped metal insert was substituted for the pad at the top of the T.

With both types of steel posts, the peak force was reached at the beginning of the impact period rather than at the point of major failure as with wood. For the steel posts, the point of major failure was the point at which the post buckled. Failures occurred at or immediately above the clamp top. After the initial buckling, the energy bent the posts against the top of the clamp.

Even though the post holder was modified to prevent twisting, three of the seven S3x5.7 posts twisted after the point of major failure (posts C, E, and G). Three of the five W6x8.5 steel posts (D, E, and G) twisted at about the time of major failure.

Figure 10.—Examples of force-time time curves for S3x5.7 and W6x8.5 steel posts (1 msec = 0.001 second). Shaded area is the impulse to point of buckling.

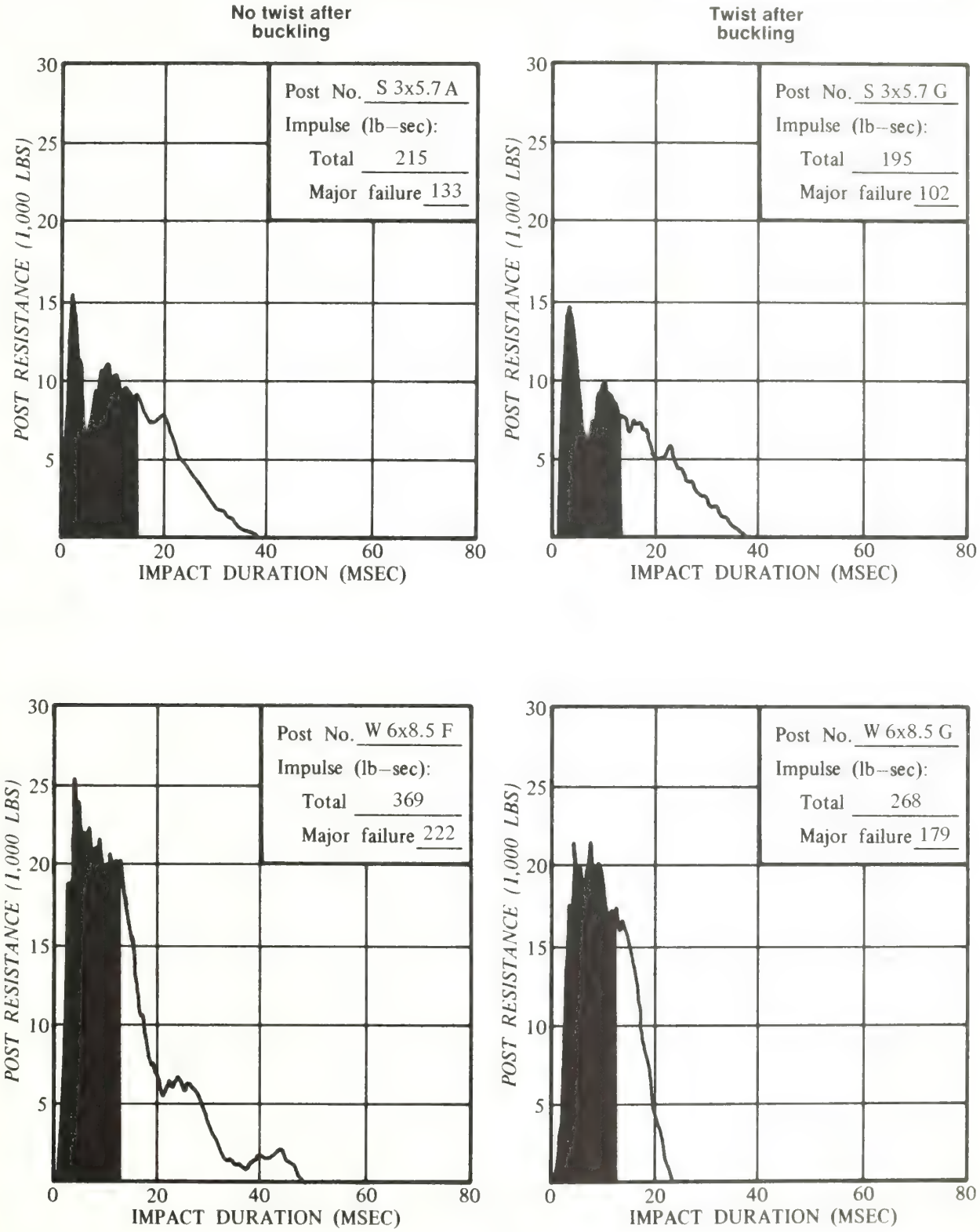


Table 3.—Steel-post pendulum-impact values to the point of major failure

Post No.	Pendulum velocity		Elapsed time	Impulse	Fracture energy	Aver. force	Displacement	Peak force
	Impact	Final						
	Ft./sec.	*Ft./sec.*	*Msec.*	*Lb-sec.*	*Ft-Kips*	*Kips*	*In.*	*Kips*
S3x5.7A	30.2	29.1	15	133	3.95	8.9	5.3	15.5
S3x5.7F	29.7	28.8	13	107	3.13	8.2	4.6	15.1
S3x5.7G	26.6	25.8	13	102	2.66	7.8	4.1	14.9
S3x5.7B	26.2	25.4	13	102	2.63	7.8	4.0	13.2
S3x5.7E	26.1	25.3	14	102	2.61	7.3	4.3	14.5
S3x5.7D	26.0	25.2	13	98	2.51	7.5	4.0	16.0
S3x5.7C	26.0	25.4	9	68	1.78	7.7	2.8	13.1
Average	27.3	26.4	13	102	2.75	7.9	4.2	14.6
W6x8.5E	29.4	27.4	14	246	6.98	17.6	4.8	28.0
W6x8.5D	30.5	28.6	13	233	6.91	18.0	4.6	24.5
W6x8.5F	27.0	25.2	12	222	5.81	18.5	3.8	25.5
W6x8.5C	26.8	25.1	10	211	5.48	21.1	3.1	28.5
W6x8.5G	26.0	24.6	12	179	4.53	14.9	3.7	21.5
Average	27.9	26.2	12	218	5.94	18.0	4.0	25.6

The S3x5.7 posts are generally considered suitable for weak-post guarding systems, while the W6x8.5 posts are used in the strongpost systems. Both types had about the same average elapsed time to major failure (12 to 13 msecs) and displacement to major failure (about 4 inches). The other S3x5.7 parameters of fracture energy, average force, and peak force were about half those of the W6x8.5 steel posts.

DISCUSSION OF RESULTS

This report can be considered somewhat biased against wood. First, in each wooden-post series, posts with strength-reducing defects were purposely included. Second, in the steel-post series, force was applied only perpendicular to the flanges and parallel to the web (the strong axis). By modifying the post holder, efforts were made to prevent steel posts from twisting. The resulting values were used as indicators of overall steel-post performance even though impact against the weak axis (perpendicular to the web) would almost certainly reduce strength performance of steel posts in actual use.

In general, the better strong post is one that provides a lower peak resistance force and a lower average resistance force while at the same time maintaining an adequate fracture energy. Peak and average forces relate to the "G" forces acting on vehicle occupants. Fracture energy relates to the ability of a guardrail system to absorb the energy of impact. The average force is determined by dividing the fracture energy by the post displacement. The more resilient posts will provide greater displacements and, as a result, lower average force values.

Considering these factors, we found that wooden posts have characteristics that are equal or superior to those of comparable steel posts. The No. 1 SR 6x6 southern pine posts were directly comparable to the S3x5.7 steel posts. The red oak 6x6 posts (fig. 11) and the southern pine 6x8 No. 1 SR posts were, overall, slightly superior to the W6x8.5 steel posts. The red oak 6x8 posts and the No. 1 Dense SR creosote-treated southern pine posts were considerably superior to the W6x8.5 steel posts (fig. 12).

In making these comparisons, we considered fracture energy first. If the guarding system will not absorb the kinetic energy of vehicle impact, then other post properties are unimportant. If the W6x8.5 steel post is selected as the standard for comparison, then for strong-posts systems the fracture energy of the red oak 6x6 posts (5.33 ft-kips) and southern

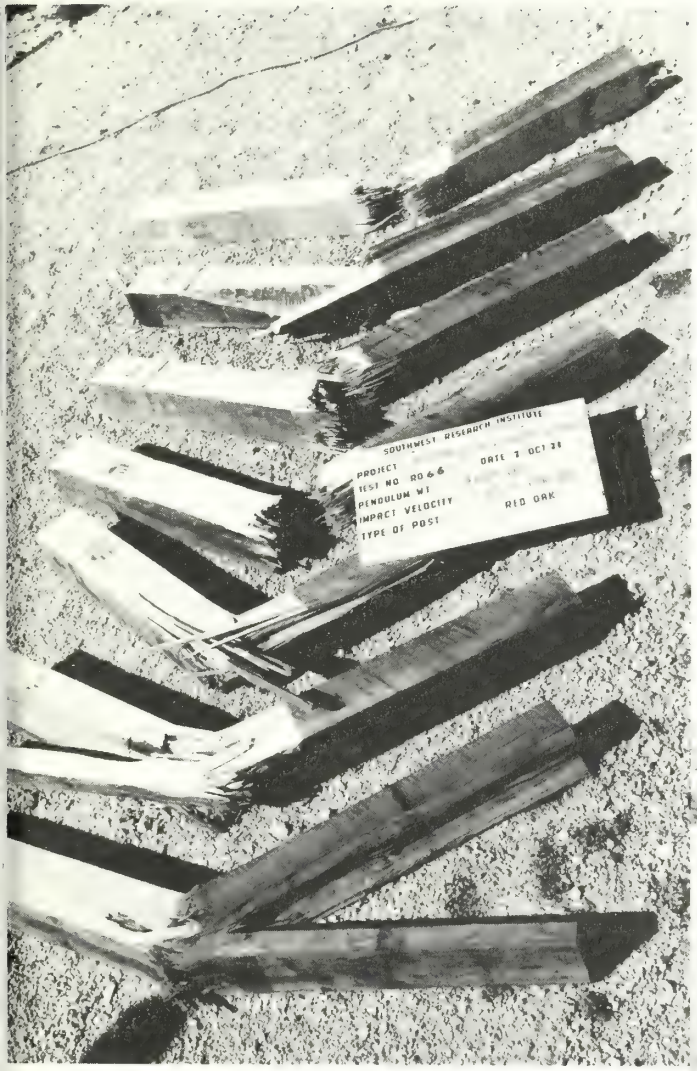


Figure 11.—Examples of wooden posts after impact testing.

Figure 12.—Examples of steel posts after impact testing.

pine No. 1 SR 6x8 posts (5.62 ft-kips) were comparable to the W6x8.5 steel posts (5.94 ft-kips).

The wooden posts were more resilient and showed greater displacements to the point of major failure. Thus the average force values for the red oak and southern pine strong posts were two-thirds those for steel. In addition, the peak forces for the strong wooden posts were only two-thirds those for steel.

An overview of all wooden posts clearly shows that the grade of wooden posts is not a true indicator of post performance in a guardrail system. More significant is the amount of grain distortion around knots in the middle third of the tension face. Knot-associated distortion over one-third or less the width of the tension face has no recognizable influence on impact strength characteristics. Knots in the middle third of the other faces or in the outer thirds of the post can be ignored. This finding suggests that states specifying 8x8-inch wooden posts that meet stress-grade requirements are overspecifying.

By eliminating from tables 1 and 2 those posts that were clearly weakened by knot-associated grain distortion, new comparisons of wooden and steel posts are possible (table 4). As the strength-reducing weak axis of the steel posts is not a factor in these values, red oak 6x6 and SP 6x8 posts can be compared very favorably with the W6x8.5 steel posts for strong-post guardrail systems.

CONCLUSIONS

1. The analysis of force-time curves and high-speed motion pictures, in combination with sample inspection, provides an excellent method for comparing the reaction to impact of various materials.
2. For strong-post guarding systems, red oak 6x6 posts and southern pine 6x8 posts provide impact-strength characteristics that are superior to those of W6x8.5 steel posts. Southern pine 6x6 posts are equal to the S3x5.7 steel posts for use in weak-post systems.
3. As a guardrail post is used in a dynamic situation, specifications for wooden guardrail posts based on grades or stress ratings can be eliminated. Wooden-guardrail-post specifications should be based on the amount of knot-associated grain distortion in the middle third of the length of the tension face. Such knot-associated grain distortion should not exceed one-third the width of the tension face.
4. Knots in the outer thirds of the length of wooden guardrail posts have no effect on impact strength and can be ignored.

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1971. DYNAMIC EVALUATION OF TIMBER POSTS FOR HIGHWAY GUARDRAILS. Highw. Res. Rep. 343: 19-33. Highw. Res. Board, Washington, D. C.

Table 4.—Average impact values for steel posts and wooden post unaffected by knot-associated grain distortion

Posts	Fracture energy	Average force	Displacement	Peak force
Wood:	*Ft-Kips*	*Kips*	*In.*	*Kips*
RO 66	5.53	11.4	5.8	18.1
RO 68	7.40	15.5	5.8	25.6
SP 66 (No. 1 SR)	3.16	8.8	4.3	14.3
SP 86 (No. 1 SR)	4.55	11.2	4.9	18.3
SP 68 (No. 1 SR)	6.86	13.1	6.3	22.0
SP 68c (No. 1 Dense SR)	7.97	14.0	6.8	21.0
Steel:				
S3x5.7	2.75	7.9	4.2	14.6
W6x8.5	5.94	18.0	4.0	25.6

Gatchell, Charles J., and Jarvis D. Michie.
1974. **Pendulum impact tests of wooden and steel guardrail posts.** NE. For. Exp. Stn., Upper Darby, Pa.
20 p., illus. (USDA For. Serv. Res. Pap. NE-311)

Impact strength characteristics of southern pine, red oak, and steel highway guardrail posts were evaluated in destructive impact testing with a 4,000-pound pendulum at the Southwest Research Institute. Effects were recorded with high-speed motion-picture equipment. Comparisons were based on reactions to the point of major post failure. Major comparisons of 6x6-inch and 6x8-inch red oak and southern pine posts with W6x8.5 and S3x5.7 steel posts showed wooden posts to be equal or superior to steel. The basis for wooden-post specifications should be the amount of knot-associated grain distortion in the middle third of the tension face of the posts. Acceptable posts are those with no single knot in the middle third of the tension face that disorients the grain for more than one-third the width of the face.

831.51:833.7:812.712

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USDA FOREST SERVICE RESEARCH PAPER NE-312
1975

NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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MANUSCRIPT RECEIVED FOR PUBLICATION 27 MARCH 1974

ABSTRACT

The relative or percentage value response after 12 years of selective cutting practices on low- and high-quality sites in Appalachian hardwoods amounted to a 119-percent increase on the low-quality site and 145 percent on the high-quality site. The absolute value or actual dollar response, on the other hand, showed that the low-quality site increased in value only $76/acre while the high-quality site increased $233/acre; or it took three low-quality site acres to every 1 high-quality site acre to attain equivalent value change. Current trends in species composition indicate that selective cutting practices will change the species composition toward a climax stand favoring shade-tolerant, slower-growing, lower-valued tree species.

Site Quality in Appalachian Hardwoods: The Biological and Economic Response Under Selection Silviculture

by Orris D. McCauley
and George R. Trimble, Jr.

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THIS IS an evaluation of the individual-tree-selection system of silviculture, based on a study of sites of two qualities in middle-aged Appalachian hardwoods. Our objectives are to compare the early biological trends in species composition, growth rates, timber quality, and reproduction characteristics by sites, and to compare monetary outcomes for the 12-year period of record based on two cuts and two inventories.

STUDY AREAS

The study was made on two areas on the Fernow Experimental Forest near Parsons, West Virginia. One area was a high-quality site (site index 75 for oak) and the other was a lower-quality site (site index 62 for oak) *(Schnur 1937)* (table 1).

The Fernow Forest is a 3,600-acre outdoor laboratory of the Northeastern Forest Experiment Station. Here the virgin forest was cut over in high-grading operations between 1905 and 1910. The stands at the inception of the management study were 50-year-old second growth with a scattering of old-growth holdover trees from the original harvest.

The climate on the Fernow Forest is normally rainy and cool, and winters are cold. Mean annual precipitation is about 58 inches, evenly distributed throughout the year. Mean annual temperature is about 48°F, and the length of the frost-free season is about 4½ months. Soils of these study areas are silt loams derived from sandstone and shale.

Table 1.—Study-area characteristics

Site designation	Oak site index	Area	Soil type	Elevation	Cuts
	Feet	*Acres*		*Feet*	*No.*
High-quality	75	78	Calvin silt loam	2,600	2
Low-quality	62	23	Calvin-Dekalb silt loam	2,500	2

SILVICULTURAL SYSTEM

The system under study is the selection system which, according to Smith (*1962*), "is applied to any silvicultural program aimed at the creation or maintenance of uneven-aged stands; the selection method is employed for the regeneration of such stands." According to FOREST TERMINOLOGY (*Society of American Foresters 1958*) an uneven-aged stand is one "in which there are considerable differences in age of trees and in which three or more age classes are represented." The terms *uneven-aged management* and *all-aged management* are commonly used interchangeably in describing this system of handling forest stands.

Although the selection system is applied in a variety of ways, it is characterized by periodic cutting of individually marked trees throughout a range of diameter classes. Generally, the marking does not extend below the smallest merchantable size class; this size is determined by the market situation in the area. In many hardwood areas, good markets have been limited until recently (and still are in some areas) to sawlog-size stems (trees larger than 11 inches dbh). This study deals with results of applying individual-tree selection to areas where the production of sawtimber was the only concern.

Most selection silviculture has been applied with only vague guidelines: such objectives as cutting a predetermined volume of timber per acre, eliminating the poor growing stock, or removing certain valuable species. However, to provide indefinitely for approximately equal cuts at more or less equal intervals (cutting cycles) and to maintain near-optimum volume growth and quality increment requires better guidelines than these. In particular, more consideration needs to be given to the residual stand density and to the diameter distribution of stems in it.

De Liocourt devised a method that has been used to guide stand structure, and it has been

described by Meyer *et al.* (*1952*). A "Q", or proportional relationship between the number of trees in different diameter classes, defines an inverse J-shaped curve (fig. 1, appendix I). For example, using a Q of 1.3 with 2-inch diameter classes means that the residual stand should contain 1.3 times as many trees in each decreasing dbh class; that is, the 16-inch class should have 1.3 times as many trees as the 18-inch class, etc. In actual practice, marking a stand to leave a given Q is usually implemented by combining the stem-size classes into such groups as poles, small sawtimber, and large sawtimber.

Determination of stand-structure guides involves not only picking a suitable diameter-distribution index, but also deciding what basal area and maximum-size tree to leave (table 1a, appendix I).

All these residual-stand parameters — Q, basal area, and maximum-size tree — are easier to apply than it might appear to those unfamiliar with the concept. The reason is that they need be only approximations. The fact that these guidelines can be approximated, however, does not mean that they are unimportant. The practice of the selection system over a long period requires a stand structure that will insure sufficient harvestable trees of the larger dbh classes.

STUDY METHODOLOGY

BIOLOGICAL

The study areas were small watersheds with surveyed boundaries. Site quality was determined from a grid system of plots, using the method of Trimble and Weitzman (*1956*), which employed the site-index curves of Schnur. Silvicultural guidelines were based on local experience and on what information was available (table 2). During the period when management was being begun, the main emphasis was on conditioning these previously unmanaged stands within the framework of the system but without undue concern for close adherence to regulation goals.

The use of a Q of 1.3, rather than the 1.5 to 1.6 ratio found locally in unmanaged stands, provides for more growing stock in the larger tree classes. This favors potentially higher returns to applied forest practices as long as it provides sufficient lower-diameter trees to grow into the next larger class. Our experience to date indicates that it does.

The goals for residual basal area, maximum-size leave tree, and cutting-cycle length (table 2) are based partly on the results of local studies of stand and individual-tree growth rates *(Trimble 1968)*.

To measure growth rates, species composition, and diameter distribution, we made periodic stand inventories; 100 percent for all trees over 5.0 inches dbh and 1 to 5 percent (1/100-acre plots on a grid) for stems 1 to 5 inches dbh. Log grade was estimated in the standing trees on a sampling basis (*Ostrander et al. 1965*). We made two inventories; one at the beginning and one at the end of the study period. The initial inventories for the study areas were completed in early 1958. The initial selection cuts were made during the dormant season of the same year. The second cuts were completed in the spring of 1968. The final inventories were made during the dormant season in 1969-70.

The initial cut in these stands (the first of the two improvement cuts) emphasized the harvesting of overmature timber (old residuals) and poorer individuals of sawtimber-size in the second-growth stand. Culls larger than 11 inches dbh were either girdled or treated with ammate crystals in chopped cups.

In the second cut, we gave more emphasis to the attainment of a balanced stand structure. The few culls that had developed in the 10-year period between cuts were girdled with a power saw by the timber faller.

ECONOMIC

To make an economic evaluation of the biological response, we used a market structure that was realistic for the study area. Because of the dynamic nature of markets, the cost–price framework selected for our analyses may not be that always used by timber buyers in the study area, but it is one that can be

Table 2.—Biological goals of management

Site designation	Q	Number of trees/acre			Residual basal area in trees over 11.0 inches dbh	Maximum size tree dbh	Gross[a] residual volume/ acre	Length of cutting cycle
		6-11 inches	12-17 inches	18+ inches				
		No.	*No.*	*No.*	*Sq. ft./acre*	*Inches*	*M bd. ft.*	*Years*
High-quality	1.3	49	22	17	70	32	12.9	10
Low-quality	1.3	52	24	8	40	20	5.5	10[b]

[a]Based on local volume tables made at initiation of stand management. Board-foot measurement is by International ¼-inch kerf rule to an 8-inch top, diameter inside bark.

[b]Indications are that on sites of this quality the cutting cycle should probably be lengthened to about 15 years.

Table 3.—Stumpage prices used for stand economic evaluation
[In dollars]

Species group number	Sawtimber species included in group	Per thousand board feet			
		Trees with butt-log grade 1	Trees with butt-log grade 2	Trees with butt-log grade 3	Trees with lower butt-log grades
1	Miscellaneous spp.[a]	$ 6	$ 6	$ 6	$ 1
2	White oak	57	16	1	1
3	Red oak	69	34	12	1
4	Yellow-poplar[b]	58	32	16	1
5	Black cherry	121	75	35	1
6	Sugar maple	87	42	9	1
7	Red maple	72	32	2	1
8	Sweet birch	91	34	1	1
9	Basswood	69	39	17	1
10	White ash	118	56	21	1

[a]Includes hemlock, bigtooth aspen, hickories, American beech, chestnut oak, elms, black gum, butternut, and other species when of merchantable size such as eastern hophornbeam, Fraser magnolia, sassafras, black locust, and sourwood (scientific names are given in appendix IV).

[b]Includes cucumbertree.

described and that provides a basis for evaluation.

The market structure we applied in this study is that used by the USDA Forest Service for stumpage appraisal on the Monongahela National Forest. It involved the use of: (1) butt-log tree grades, (2) stumpage prices by tree grade, and (3) species grouping based on grade and price levels (table 3). The prices used are net sums developed from an analysis of grade-lumber recovery values, minus total lumber-conversion costs.

For low-grade trees, conversion costs can exceed tree value, resulting in negative stumpage values. To avoid negative values in the analysis, all negative stumpage-appraisal prices were assigned positive $1.00-per-thousand-board-foot values. For this reason, all merchantable trees below butt-log grade 3 were arbitrarily grouped and assigned a value of $1.00 per thousand board feet.

The values for analysis and evaluation were derived by applying butt-log grade and price information (table 3) to volume of the original and subsequent inventories and to the volume removed by each harvest.

Costs of 1¢ per diameter inch were used to determine the cost of cull removal. These costs were deducted from the returns as they were incurred.

The per-acre values shown in this report are net summations of periodic inventory value or harvest incomes.

All stumpage prices and costs used in the evaluation were maintained at a constant level to avoid the change in money values due to inflation. Furthermore, implicit in our constant-price assumption is that all products would sell in the market at the quoted prices.

Because the product goal is realistically restricted to the sale and value of sawtimber alone, the stand valuation excludes growing-stock values and investment costs for trees below sawtimber size in the investment analyses. Under this treatment and product goal, growing-stock volume is valued as the trees attain the minimum sawtimber dbh of 11.0 inches.

RESULTS

BIOLOGICAL

To determine the effects of site on stand characteristics, we examined a number of features. We compared species composition of all size components of the stand; we determined stand growth rates in board feet and basal area; we appraised timber quality in terms of log grade, scaling deductions, and cull trees; we surveyed the origin, number, and distribution of reproduction stems, and we looked at stand structure as it was affected by the two cuts.

Species Composition

Both sites contained a large number of different commercial species, and this was true of all the stand segments we looked at: the 1- to 5-inch stems, the 5- to 11-inch stems, and the stems over 11.0 inches dbh — the sawtimber stand (table 4).

We looked primarily for two kinds of relationships in species compositions: relationship to site quality and relationship to cutting practice. (See appendix IV for a list of tree species found in study area.)

In examining the relationship to site, we looked first at the stand over 11.0 inches dbh as it was before initiation of management. We found that, on the high-quality site, 30 percent of the stems were composed of the more desirable commercial intolerants, black cherry and yellow-poplar; but on the low-quality site the stand showed only about 8 percent of these species. The oaks, less demanding in site quality, made up about 23 percent of the overstory on the high-quality site and about 44 percent of the stands on the lower-quality site. Both of these species relationships to site quality are typical.

In examining the advanced reproduction for site-related effects, we found that, after two cuts, sugar maple and beech were most numerous on the good-quality site and beech and red maple on the low-quality site.

To get an indication of the effects of the cutting practice on species composition, we compared the 1- to 5-inch stems of advanced reproduction (tallied at the second inventory) to the 11.0-inch-plus overstory as it was before the first cut. The advanced reproduction came in under a full to partial canopy; the overstory resulted from a commercial clearcut in the virgin forest and from wildfire.

On the high-quality site, black cherry and yellow-poplar made up 30 percent of the overstory stems before the first cut but less than 1 percent of the advanced reproduction. The shade-tolerant sugar maple, beech, and red maple made up 26 percent of the overstory but 87 percent of the advanced reproduction. On the lower-quality site, the oak group made up 44 percent of the overstory but only about 8 percent of the advanced reproduction. Individual-tree-selection cutting is reducing black cherry and yellow-poplar on the high-quality site and reducing oak in the low-quality site. Indications are that, in the future mature stands on the high-quality site, sugar maple and beech will predominate; and on the low-quality site, beech and red maple will make up over half the stems.

Growth

The stands were well stocked at the beginning of management. Basal area in trees over 5.0 inches dbh ranged from 95 to 114 square feet. This is well above the minimum level that Fernow studies have shown to be adequate for maximum growth on these sites (*Trimble 1968*). After the second cut, stocking was still well above the minimum level (table 5).

Computed growth included both accretion

Table 4.—Species composition of merchantable tree stands

[Most numerous commercial species are listed in numerical order and as percentage of total stand]

1- to 5-inch stems		5- to 11-inch stems		Trees over 11 inches	
Before first cut	After second cut	Before first cut	After second cut	Before first cut	After second cut
HIGH-QUALITY SITE					
Percentage	*Percentage*	*Percentage*	*Percentage*	*Percentage*	*Percentage*
Sugar maple 42.7	Sugar maple 42.8	Red oak 14.1	Sugar maple 16.0	Black cherry 17.2	Red oak 24.2
Beech 33.8	Beech 34.2	Sweet birch 12.5	Sweet birch 13.2	Red oak 15.6	Black cherry 16.9
Red maple 10.3	Red maple 9.8	Sugar maple 7.8	Red maple 10.7	Beech 15.4	Yellow-poplar 14.4
Sweet birch 4.6	Basswood 2.4	Red maple 7.7	Red oak 10.0	Yellow-poplar 12.5	Beech 11.3
Red oak 2.6	Fraser magnolia 2.1	Black cherry 7.6	Beech 9.8	Sugar maple 7.4	Sugar maple 5.8
Cucumber 1.0	Sweet birch 1.8	Black locust 7.4	Cucumber 6.0	Chestnut oak 4.7	Chestnut oak 5.0
Hickory .9	Red oak 1.5	Beech 6.9	Chestnut oak 4.6	Sweet birch 4.7	Sweet birch 4.6
Yellow birch .7	Black locust 1.2	Chestnut oak 5.6	Black cherry 4.2	Hickory 4.1	Red maple 4.0
Basswood .7	Black gum 1.2	Yellow-poplar 5.3	Yellow-poplar 3.8	Red maple 2.9	Hickory 2.7
Black gum .7	Cucumber .9	Cucumber 5.3	White ash 3.7	Black gum 2.9	White oak 2.2
Hophornbeam .5	Hickory .6	White oak 4.9	Black locust 3.2	White oak 2.5	Cucumber 2.1
Miscellaneous 1.5	Miscellaneous 1.5	Miscellaneous 14.9	Miscellaneous 14.8	Miscellaneous 10.1	Miscellaneous 6.8
LOW-QUALITY SITE					
Beech 34.4	Beech 40.9	Sassafras 21.6	Red maple 16.6	Red oak 22.1	Red oak 32.4
Red maple 20.0	Red maple 19.0	Red oak 13.1	Red oak 14.8	Chestnut oak 19.8	Chestnut oak 21.3
Sugar maple 11.4	Fraser magnolia 8.7	Fraser magnolia 11.1	Fraser magnolia 10.7	Beech 14.8	Red maple 9.2
Red oak 8.0	Sweet birch 6.8	Red maple 11.0	Sassafras 10.3	Black gum 10.0	Beech 7.9
Sweet birch 5.5	Red oak 4.9	Chestnut oak 10.1	Chestnut oak 10.0	Red maple 7.2	Fraser magnolia 5.5
Fraser magnolia 5.1	Black gum 4.8	Sourwood 7.2	Sweet birch 8.3	Yellow-poplar 5.1	Yellow-poplar 4.8
Sassafras 4.4	Sourwood 3.8	Black locust 5.6	Sourwood 7.8	Sweet birch 3.7	Black gum 3.1
Chestnut oak 3.2	Sugar maple 3.1	Sweet birch 5.2	Beech 7.0	Black cherry 3.1	Black cherry 2.5
Hophornbeam 2.5	Chestnut oak 2.0	Beech 4.9	Cucumber 3.9	Fraser magnolia 2.4	Sweet birch 2.4
White oak 2.5	Cucumber 1.6	Cucumber 3.3	Black locust 3.0	White oak 2.2	White oak 2.3
Black gum 1.3	Black locust 1.4	Black cherry 1.4	Sugar maple 1.5	Hickory 2.1	Cucumber 1.9
Miscellaneous 1.7	Miscellaneous 3.0	Miscellaneous 5.5	Miscellaneous 6.1	Miscellaneous 7.5	Miscellaneous 6.7

Table 5.—Periodic annual growth per acre

Site designation	Board-foot growth[1]		Basal area at last inventory		Basal-area growth in trees over 5.0 inches
			In trees over 5.0 inches	In trees over 11.0 inches	
	Bd. ft.	*Pct.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
High-quality	385	3.1	99	71	2.0
Low-quality	249	3.4	89	47	2.3

[1]International ¼-inch kerf rule, to an 8-inch top dib, in trees over 11.0 dbh.

Table 6.—Per-acre volumes, merchantable and cull

Site designation	Before first cut				After recruise 12 years later			
	Merchantable volume	Cull-tree volume	Total volume	In cull trees	Merchantable volume	Cull-tree volume	Total volume	In cull trees
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Pct.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Pct.*
High-quality	11,179	1,390	12,569	11.06	11,230	24	11,254	0.21
Low-quality	6,115	1,233	7,348	16.78	5,624	17	5,641	.30

(growth on residual trees above the minimum sawtimber diameter) and ingrowth, but excluded mortality. Board-foot and basal-area growth computations included volumes cut as well as growth on standing trees.

During the study period, annual growth on the high-quality site was 385 board feet per acre and on the lower-quality site 249 board feet (table 5). With a site difference between sites of about 13 feet of site index, the average annual growth advantage of the better site was about 10 board feet for each foot of site index.

Annual basal-area growth in trees over 5.0 inches dbh ranged from 2.0 to 2.3 square feet; and if there was a relationship to site quality, it was masked by the effects of other stand variables.

Timber Quality

Timber quality of sawlog-size trees was measured by: (1) the volume of the cull trees in the stand, (2) defective material in merchantable trees, and (3) the grade of logs in merchantable trees.

Total inventories gave us the volume in cull trees; scaling records provided an estimate of volume in defects; and sample-tree grading during the inventories yielded an estimate of log grade in the sawtimber stand.

Through the girdling of cull trees, the percentage of stand volume in these trees was reduced from 11.06 to 0.21 in the high-quality site area; from 16.78 to 0.30 percent for the low-quality site area (table 6). We see no relationship in these figures to site quality. At each harvest, all cull trees over 11.0 inches dbh in the stand were killed. (A cull tree was defined as a tree over 11.0 inches dbh that does not contain at least one 16-foot log having 50 percent or more of merchantable volume.) The drastic reduction in cull-tree volume was in accord with results from similar practices on other areas (*Trimble 1965, Trimble 1970*).

Scaling deductions dropped sharply from the first to the second cut, as follows: high-quality site from 9.3 to 5.2 percent, low-quality site from 17.0 to 6.6. These deductions included cull logs in merchantable trees that were not butted off before skidding; they also included crook, sweep, shake, and rot in merchantable logs.

Table 7.—Percentage of stand sawlog volume by butt-log grade

Butt-log grade	Before first cut	In first cut	In second cut	After second cut
	HIGH-QUALITY SITE			
1	11.9	1.9	17.4	30.0
2	11.3	4.3	20.3	23.0
3	42.1	31.3	44.4	36.0
4 and 5	32.8	60.7	12.9	10.1
6	1.9	1.8	5.0	.9
	LOW-QUALITY SITE			
1	14.2	6.3	25.1	29.1
2	16.1	15.2	15.0	24.6
3	32.3	16.3	34.1	37.9
4 and 5	33.9	55.6	20.3	7.9
6	3.5	6.6	5.5	.5

Factory-log grades 1 and 2 make up the bulk of the money value in a stand. The silviculture practiced over the study period has raised the percentages of sawtimber volume in these two grades (table 7). For the high-quality site the increase was from 23.2 percent to 53.0; for the low-quality site the increase was from 30.3 to 53.7. The improvement in grade was also strongly reflected in the large percentage increase in the number of trees moving from log grade 2 to log grade 1 between the first and second cuts.

Reproduction Characteristics

We used the 1- to 5-inch stems, or advanced reproduction, to indicate the trend of stand regeneration resulting from a single cutting practice (individual tree selection cutting) applied on sites of contrasting quality.

The number of advanced reproduction stems per acre after the second cut was 323 for the high-quality site and 492 for the low-quality site. Eleven percent of the stems on the high-quality site and over 16 percent on the low-quality site were sprouts (table 8).

The percentage of good stems (potentially good-quality sawtimber trees) by areas ranged from 74 for the low-quality site to 89 for the high-quality site (table 8).

In all stands, the advanced reproduction stems of commercial species were well dis-

Table 8.—Number, distribution, origin and quality of 1-to 5-inch stems of commercial species after two cuts

Site designation	Stems per acre	Sprouts	Good-quality stems	Sampled 1/100-acre plots stocked with commercial species
	No.	*Pct.*	*Pct.*	*Pct.*
High-quality	323	11.0	89.3	87.5
Low-quality	492	16.8	73.9	94.7

tributed. On the high-quality site, 88 percent of the sampled 1/100-acre plots contained stems, as did 95 percent of the plots on the low-quality site.

Stand Structure

Average Q's and numbers of trees by diameter groups were compared for three time periods (table 9); (1) before the first cut, (2) at the second inventory, and (3) when management goals are attained (a situation anticipated at some time in the future).

The number of trees in the 5- to 11-inch dbh group is not controlled, because no cutting is done below sawlog size — 11.0 inches. As is evident (table 9), the number of stems in this size group is far more than enough to supply the stems needed in the 11- to 17-inch class (small sawtimber). In other words, there is no indication that we are going to run out of trees to cut. To the contrary, the excessive number of poles indicates that in the absence of cutting in the stand below sawtimber size, we are probably providing unfavorable conditions (too much competition) for the best growth of sawtimber-size trees. The net result will be a less valuable periodic harvest; a higher proportion of the harvest will be ingrowth (12- and 14-inch trees) than would be the case if we were also periodically harvesting trees from the 5- to 11-inch stand.

During the period of management, size of sawtimber trees has changed little, as indicated by the average dbh of merchantable trees over 11.0 inches (table 10).

Table 10.—Average dbh of sawtimber trees, in inches

Site designation	Before first cut	After second cut	Goal of management for residual stand
High-quality	15.6	16.0	17.4
Low-quality	15.1	15.0	15.0

ECONOMIC

Economic evaluations can be developed and applied to a forest practice by using the biological response by site quality. The primary emphasis here is to demonstrate valuation techniques and the application of various investment measures that can serve as the basis for decision-making.

In arriving at a decision to invest in a forest practice, the investor usually reviews all the expected returns and risks associated with the investment. He has the opportunity, first, to invest his savings in a savings bank — with little if any risk. Or he can use it for other investments and earn greater or smaller returns, usually with more risk of loss.

This opportunity to invest in a savings account or some alternative other than timber should logically be included as a cost of the timber investment. If the market rate of interest is 5 percent, then the investor would

Table 9.—Stand diameter distribution per acre

Site designation	Q			Number of trees by diameter groups (inches)								
	Before first cut	At second inventory	Management goal	Before first cut			At second inventory			Management goal for residual stems		
				5-11	11-17	17+	5-11	11-17	17+	5-11	11-17	17+
High-quality	1.8	1.6	1.3	98	38	14	87	32	16	49	22	17
Low-quality	2.1	1.7	1.3	146	29	9	135	28	9	52	24	8

have $105 at the end of the first year for every $100 invested. And this amount, $105, is compounded, not treated as an investment at simple interest. By investing in his timber stand, the forest manager has foregone the $5 interest he could have earned in his savings bank. Thus, in long-term investment analysis, an appropriate compound or discount rate should be used in evaluating an investment rather than a simple interest rate.

Stand Valuation

To develop the economic measures, we have assumed certain measurement criteria as constant for the 12-year study period. In addition to constant prices and dollar values, we have assumed equal borrowing and lending rates — which are seldom the same in the money markets. Furthermore, the decision about an investment depends on all costs. We have assumed in our analysis that the original sum invested in land was at no cost. Money to invest is assumed to be derived from savings, or reserve funds, or borrowed from a lending agency at the market rate of interest.

Using the cost–price structure referred to earlier, we computed values for the timber inventory before the first cut, the inventory after the second cut, and for the volume removed during each cut.

Expressed in terms of average timber value per acre, the low-quality site increased from $64/acre in 1958 to $140/acre in 1970, an increase of $76/acre. During the same period, the high-quality site's timber value increased from $161/acre to $394/acre, an increase of $233/acre. These figures do not include the value of timber cut.

Another way of showing the improvement in stand value was to express the percentage of stand sawlog value in the different log grades (table 11). The results show that stand value in log grades 1 and 2 has increased from 61 to 86 percent on the high-quality site and from 68 to 86 percent on the lower-quality site. More important than the increase in stand value in log grades 1 and 2 was the reduction in percentage of total value found in the low-quality grades. After the second cut, both stands had less than 15 percent of the total volume in log grade 3 and below. This means that more of the volume growth is on high-quality stems, thus increasing the overall value of the stands.

Table 11.—Percent of stand sawlog value, by log grade and site

Log grade	Before first cut	In first cut	In second cut	After second cut
	HIGH-QUALITY SITE			
1	41	25	55	63
2	20	15	24	23
3	36	50	21	14
Other	3	10	+	+
	LOW-QUALITY SITE			
1	50	51	70	62
2	18	10	16	24
3	28	31	12	14
Other	4	8	2	+

Caution must be exercised in interpreting the increase in value on the two sites. Although the relative increases are not much different — 119 percent for the low-quality site and 145 percent for the high-quality site — the absolute change in the value is much greater for the high-quality site — $233 compared to $76. This means that it takes three low-quality site acres of timber to each high-quality site acre to produce timber of equivalent value. Basically the difference resulted from the high-quality site having better species (in respect to inherent value and grade improvement) and higher growth rates.

Stand Investment

Internal Rate of Return

Internal rate of return (IRR) provides the forest manager or decision-maker with a criterion for measuring how well an investment has performed or is expected to perform. The internal rate of return is that discount rate that will shrink expected or earned incomes from an investment so that it equals the initial cost of the investment. For example, we calculated the internal rate of return by slightly modifying the discount formula:

$$V_o = \frac{R_1}{(1+i)} + \frac{R_2}{(1+i)^2} + \cdots \frac{R_n}{(1+i)^n}$$

In the equation, V_o is the beginning value of the investment in timber, or in other situations, the cost of applying a forest practice; R_1, R_2 . . . R_n are expected or earned net incomes from the investment, the subscript representing the year in which a specific income occurred; i is the discount rate that shrinks the income stream (R's) so that the sum of discounted incomes is equal to V_o, the investment.

In application, since i is unknown and appears in several terms, a trial-and-error process is usually used to find the i that satisfies the equation. That is, a trial i is used to discount each R to the beginning of the investment period. If the sum of discounted R's is larger than V_o, select a larger i and repeat. Resolve until the sum of discounted incomes is approximately equal to V_o.

Normally, the internal rate of return is used to find the rate of return from an expected or estimated future income stream resulting from an investment, but it can be used as well to discount incomes after they have been earned, as we have applied it in our site evaluation. In table 12 we have listed the application of the internal rate of return to our study.

For each site we show the discount period or the year the income was earned, n, in column 1; original stand value or investment, V_o, in column 2; the net income stream, R, in column 3; and the factor $(1+i)^n$ in column 4.

Using the trial-and-error method and substituting these values in the IRR equation for our site-quality classes, we find that a discount rate of 9.7 percent most nearly equates the flow of net incomes from the high-quality site with the initial investment of $161.46/acre. Likewise, a 10.6-percent discount rate most nearly equates the low-quality site income stream with the initial investment of $63.68/acre. See appendix II for the trial-and-error calculations.

These are relatively high returns for an investment in timber on either high- or low-quality sites, the low-quality site exceeding that of the high-quality site at least for the 12-year period. But we must recognize exactly what we have measured with the IRR, how to apply and interpret the investment measurement, and the conditions and constraints that might affect the size of the IRR.

First, when using the IRR, we are looking at an investment within the business rather than of the total business investment and the total flow of expected net income (returns minus costs), which involves outside factors such as the cost of borrowing funds. Often it

Table 12.—Values used to compute the Internal Rate of Return for the high- and low-quality site investment

Equation symbol								
n (1)	V_o (2)		R (3)		$(1+i)^n$ (4)			
Discount period or year income earned	Beginning investment/acre		Net income/acre		Discount factor at given interest rate[a]			
	Low site	High site	Low site	High site	9.7%	9.8%	10.5%	10.6%
0	$63.68	$161.46	——	——	——	——	——	——
1	——	——	$14.65	$13.72	1.097	1.098	1.105	1.106
2	——	——	——	——	1.203	1.206	1.221	1.223
.	——	——	——	——	——	——	——	——
.	——	——	——	——	——	——	——	——
.	——	——	——	——	——	——	——	——
.	——	——	——	——	——	——	——	——
10	——	——	23.24	50.32	2.524	2.547	2.714	2.739
12	——	——	140.28	394.13	3.037	3.071	3.314	3.350

[a]From Marty and Neebe 1966.

is difficult to separate the flow of income attributable to a forest-practice investment from the income stream that would have occurred if the investment had not been made.

Second, in arriving at our IRR's, we have held stumpage prices at a constant level. This is a bit unrealistic, but in practice we do this to avoid value change caused by changing prices. The value change we want to measure is the one expressed by growth and quality development in the stand. Ordinarily, over short periods of time we would not expect stumpage prices to change; but when they do, the forest manager must recognize and make adjustments for all changes that increase or decrease the flow of income from the investment.

A third factor that must be considered when interpreting the IRR for an investment is an adjustment for risk and uncertainty for losses due to fire, weather damage, and insect attacks. The probability of such losses is always present, and it fluctuates over time and with location.

A fourth condition to be reckoned with in applying the IRR is that we are measuring the relative or percentage change in value. Thus in our analysis, we show the low-quality site having a greater relative value change over the study period, 10.6 percent versus 9.8 percent for the high-quality site. In absolute or actual-dollar value, the low-quality site increased from \$64/acre to \$140/acre for a net increase of \$76/acre while the high-quality site increased from \$161/acre to \$394 /acre or \$233/acre.

The stand age and stage of development of the stand also influence the outcome and size of the IRR. Certainly the flow of income from a young developing stand differs from that of a mature stand. Likewise, the income flow from an older stand producing salable sawtimber is lumpy. We would expect the IRR of a timber investment in sawtimber to be at its maximum during the period when the stand is making its greatest growth and quality development. Similarly, where improvement costs are low, as we have demonstrated in our site-quality studies, the value change, expressed by placing volume growth on higher valued stems, will result in a more favorable IRR.

Net Future Value

A forest investor or manager may express an income goal that must be satisfied before he decides to invest. Specifically, his decision to invest may be based on a rate of interest that will satisfy an expected future value for the investment. Net future value (NFV) is a concept that can be applied in such a case to provide the manager with an estimate of the outcome of his investment.

To find the net future value we use the compounding process wherein:

$$V_n = V_o\ (1+i)^n$$

When: V_n = The net future value of an investment at the end of investment period.

V_o = The value of the investment at the beginning of the investment period.

n = Length of the investment period, in years.

i = The compounding rate; the rate of interest the manager desires on the investment.

We illustrate in simple form how the net future value of an investment is applied, using our own site-quality values for the low-quality site and assuming no income from cutting. As forest managers, we specify that our investment in the forest must earn at the rate of 5 percent or better during 12 years. What future timber value/acre at the end of 12 years is necessary to earn this rate of interest on the investment? Using the net-future-value equation, we find:

V_o = \$63.68 = the original investment in the timber stand.

n = 12 years, the number of years the \$63.68 has been invested in the timber stand.

$(1+i)^{12} = 1.79586$ = factor for 5-percent compounded interest for 12 years, found in compound interest tables.

Then, substituting the low-site values in the net-future-value equation, $V_n = V_o\ (1+i)^n$, we find:

$V_n = \$63.68\ (1.79586) = \$114.36$

In table 13, we show the performance of timber sites at varying rates of interest. (We have rounded our values in the table to the nearest whole number.) Values shown in column 3 were calculated in the same manner as above, using the net-future-value equation and compounding the $64 investment in column 2 at the interest rates shown in column 1. In column 4, we show the net value difference between what the manager or owner specified as his goal in the investment compared to the performance of our site-quality stands for the 12-year period.

For example, if the manager or owner would accept breaking even (zero interest) in making an investment ($64/acre) in our low-quality site stand, at the end of 12 years he would have received his $64 back plus a bonus of $76. The actual low-quality site value at the end of 12 years was equal to $140/acre; then by subtracting the value in column 3 from $140, we arrive at the value shown as surplus or loss in column 4.

When the specified interest rate is equal to 6.8 percent, the net future value or required value of the original investment ($64) after 12 years is equal to $140/acre. At the end of the 12-year period, the low-quality site stand was valued at $140/acre. We have equated the original investment at an interest rate that equals the actual stand value after 12 years. Stated in another way: when the value of the stand after 12 years is equal to $140/acre, the performance of the stand is equal to an investment of $64/acre for 12 years at 6.8 percent compound interest. (In the IRR solution, the rate earned was 10.6 percent when revenues from timber cut were included.) Table 13 shows that, at interest rates greater than 6.8 percent, the required stand value (the net future value of an investment of $64/acre for 12 years) would exceed the actual performance of the low-quality site.

Our illustration above shows the application of the net-future-value concept in an elementary form to our site-quality evalua-

Table 13.—Stand performance based on net future value and owner's desired rate of interest on investment

[In dollars]

Rate of interest (percent)	Beginning or initial investment/acre, 1958	Required value in 1970/acre for stand to earn indicated interest rate (net future value)	12-year results: surplus/acre[a]
		LOW-QUALITY SITE	
0	$64	$64	$76
2	64	81	59
3	64	91	49
4	64	102	38
5	64	114	26
6	64	128	12
6.8	64	140	0
8	64	160	−20
10	64	200	−60
		HIGH-QUALITY SITE	
0	161	161	233
2	161	205	189
3	161	230	164
4	161	258	136
5	161	290	104
6	161	325	69
7.7	161	393	1
8	161	407	−13
10	161	507	−113

[a]These figures are the difference between the actual stand values in 1970 ($140 for low-quality site stand, $394 for high-quality site stand) and the required stand value in 1970.

tion as a measure of the effectiveness of our initial investment. In a forest business, the total net cash flow or net income stream from the investment must be accounted for to show the true performance and effectiveness of the investment. Column 4 of table 13 shows only the difference in value of our initial investment at a desired rate of interest and the end value after 12 years. The net income from the harvest or improvement cuts made since the initial investment is a part of the total income stream from the initial investment, and logically it should be reinvested. We can calculate the true net future value of the initial investment by slightly modifying the basic net-future-value equation to include the income from cuts as well as ending-inventory value. The equation modification and computations for inclusion of total income flow are shown in appendix III.

Other Investment Considerations

Up to this point, in our economic analyses we have considered as a cost only the initial value of the timber. To provide additional realism in evaluation, we now include the costs of land, managerial costs, and tax costs. As will be seen, the addition of these costs does not change the relative ranking of the high- and low-quality sites. However, addition of these costs to the investment does illustrate how they change the investment opportunity and outcome.

This evaluation is made on the assumption that timber alone must carry the total investment cost. Under this assumption, we ignore other income possibilities. Some of these, such as increases in land values, may require no added investment, while others — such as leasing hunting rights — may require additional labor and managerial costs.

In our analyses, we have combined managerial and tax costs under the heading of *annual management-tax costs* for ease in computing and presenting the tables. As investment costs, they are subject to and accounted for by the same investment equation in the analyses.

Timber and land investment. — Our first example shows the possible investment outcome on high-quality and low-quality sites where the forest owner considers only the land and timber-investment costs (table 14). Using our 12-year record of the applied silviculture, we show under varying land costs and interest rates how the investment opportunity changes.

To calculate the values shown in table 14 we apply the previously explained net-future-value equation, $V_n=V_o\ (1+i)^n$. Since both land and timber costs are part of the initial investment, we use the sum of these two values. For example, to find the stand value/acre necessary to earn 5 percent on the investment after 12 years when land costs are \$10/acre, we find: V_o=\$63.68/acre (timber cost) +\$10/acre (land cost) =\$73.68/acre (total cost); $(1+i)^n=(1+.05)^{12}=1.79586$; then, V_n=\$73.68/acre (1.79586) =\$132.32/acre. The other stand values shown in table 14 were computed in the same manner at various interest rates and land values. The investment opportunity changes with investment costs.

To further explain the use of table 14, we use the low-quality site investment and an investor's desire for a 5-percent rate of interest on his land and timber investment. He could be successful only if he paid \$14/acre or less for his land and a sawtimber inventory valued at \$64/acre or a total investment of not more than \$78/acre (V_n=\$78 (1.79586) =\$140.08).

If the investor paid \$79/acre, our data show, the stand would have to reach a value of \$142/acre (V_n=\$79 (1.79586) =\$141.87) in 1970 to earn 5 percent in the investment, when in fact it was valued only at \$140/acre. Similarly, the high-quality site would earn the forest owner more than 6 percent on an investment if the land cost less than \$35/acre.

The values under the heavy lines in table 14 all exceed the average per-acre value attained during the 12-year study period; these values would be necessary to earn the indicated percentage return.

Timber and management-tax investment.— For situations where a forest owner does not consider land cost as a part of his investment, we show how taxes and management costs might influence the timber investment in forest practices (table 15).

Table 14.—Investment in stand: possible returns after 12 years of uneven-aged cutting at indicated land and timber investment

[In dollars]

Investment per acre			Stand value/acre necessary to earn the indicated interest rate after 12 years[a]					
Initial land cost	Initial timber value	12-year total	2%	3%	4%	5%	6%	7%
		LOW-QUALITY SITE						
$10	$64	$74	$93	$105	$118	$132	$148	$166
15	64	79	100	112	126	141	158	177
25	64	84	112	126	142	159	178	200
35	64	99	125	141	158	177	199	222
50	64	114	144	162	182	204	229	256
75	64	139	176	198	222	249	279	312
100	64	164	208	233	262	294	329	369
125	64	189	239	269	302	339	380	425
150	64	214	271	305	342	384	430	481
		HIGH-QUALITY SITE						
10	161	171	217	244	275	308	345	386
15	161	176	224	252	283	317	355	397
25	161	186	236	266	299	335	375	420
35	161	196	249	280	315	353	395	442
50	161	211	268	301	339	380	425	476
75	161	236	300	337	379	425	476	533
100	161	261	332	373	419	470	526	588
125	161	286	363	408	459	514	576	645
150	161	311	395	444	499	559	627	701

[a]Values to the right of the heavy lines and the indicated interest rates are unattainable because the maximum value/acre generated after 12 years was $140 for low-quality site stand, $394 for high-quality site stand.

Table 15.—Investment in stand: possible returns after 12 years of uneven-aged cutting at indicated management-tax and timber-investment costs

[In dollars]

Investment per acre			Stand value/acre necessary to earn the indicated interest rate after 12 years[a]					
Annual management-tax cost	Initial timber value	12-year[b] total	2%	3%	4%	5%	6%	7%
		LOW-QUALITY SITE						
$0.50	$64	$70	$87	$98	$109	$122	$136	$152
1.00	64	76	94	105	117	130	145	161
1.50	64	82	101	112	124	138	153	170
2.00	64	88	108	119	132	146	162	179
2.50	64	94	114	126	140	154	170	188
3.00	64	100	121	133	147	162	179	197
3.50	64	106	128	140	155	170	187	206
4.00	64	112	134	148	162	178	196	215
4.50	64	118	141	155	170	186	204	224
		HIGH-QUALITY SITE						
0.50	161	167	211	237	266	298	333	373
1.00	161	173	218	244	274	306	342	382
1.50	161	179	225	251	281	313	350	390
2.00	161	185	232	259	289	322	359	399
2.50	161	191	238	266	296	329	367	408
3.00	161	197	245	273	304	338	375	417
3.50	161	203	252	280	311	346	384	426
4.00	161	209	258	287	319	354	392	435
4.50	161	215	265	294	326	362	401	444

[a]Includes initial timber investment plus annual costs carried at interest to end of the period.

[b]Values to the right of the heavy lines and the indicated interest rates are unattainable because the maximum value/acre generated after 12 years was $140 for low-quality site stand, $394 for high-quality site stand.

For this kind of investment, where there is an annual increase in the amount of invested capital of a portion of the total investment such as the management-tax increment, we must use two equations to find net future value of the total investment. Again we use the net-future-value equation $V_n = V_o (1+i)^n$ for the timber cost portion of the investment. For the management-tax cost, we use the terminable series equation,

$$V_n = \frac{V_o (1+i-1)^n}{i} \text{ or total NFV} = V_n =$$

$$Vo_1 (1+i)^n + Vo_2 \frac{(1+i-1)^n}{i}$$

when:

$V_{o\,1}$—The timber investment.

$V_{o\,2}$=The annually recurring management-tax cost.

In applying the equation to show how the values in table 15 are computed, we use the low-site annual management-tax cost of $1.50 /acre found in column 1, the timber-investment cost of $64/acre found in column 2, and an interest rate of 5 percent found in column 7. Substituting in the total net-future-value equation, we find:

$$\text{Total NFV} = \$63.68\ (1+.05)^{12} + \frac{\$1.50\ (1.05-1)^{12}}{.05}$$

$$= \$63.68\ (1.79586) + \frac{\$1.50\ (.79586)}{.05}$$

$$= \$114.60 + \$23.88$$

$$= \underline{\$138.48}$$

Using the results of our analyses for the 12-year study period and the equations shown above, we show the investment outcome at varying annual management-tax costs for the two sites (table 15). If the management-tax costs were $1.50/acre on the low-quality site, we could attain a 5-percent return; on the

Table 16.—Investment in stand: possible returns after 12 years of uneven-aged cutting at indicated management-tax, land, and timber-investment costs

[In dollars]

Investment per acre				Stand value/acre necessary to earn indicated interest rate after 12 years[a]					
Annual management-tax cost	Initial land cost	Initial timber value	12-year[b] total	2%	3%	4%	5%	6%	7%
				LOW-QUALITY SITE					
$0.50	$10	$64	$80	$100	$112	$125	$140	$157	$175
1.00	15	64	91	113	126	141	157	175	195
1.50	25	64	107	133	148	165	183	204	227
2.00	35	64	123	152	169	188	209	232	258
2.50	50	64	144	178	198	220	244	271	301
3.00	75	64	175	216	240	267	297	330	366
3.50	100	64	206	255	283	315	350	388	431
4.00	125	64	237	293	325	362	403	447	497
4.50	150	64	268	331	368	410	455	506	562
				HIGH-QUALITY SITE					
.50	10	161	177	224	252	282	316	353	395
1.00	15	161	188	237	266	298	333	372	415
1.50	25	161	204	257	287	321	359	400	447
2.00	35	161	220	276	308	345	385	429	478
2.50	50	161	241	302	337	376	420	468	521
3.00	75	161	272	340	380	424	472	526	586
3.50	100	161	303	379	422	471	525	585	651
4.00	125	161	334	417	465	519	578	644	717
4.50	150	161	365	455	507	566	631	703	782

[a]Includes initial land and timber investment plus annual costs carried at interest to the end of period.

[b]Values to the right of the heavy lines and the indicated interest rates are unattainable because the maximum value/acre generated after 12 years was $140 for low-quality site stand, $394 for high-quality site stand.

high-quality site at the same management tax rate, a return greater than 7 percent would be possible.

Timber, management-tax, and land investment. — The opportunity for investment in forest land is less attractive when all costs are chargeable to the productivity of the timber stand. For such cases we have computed the timber-investment outcome for our study sites under varying land and management-tax costs (table 16).

To calculate the values shown in table 16 for the various costs and interest rates, we use the NFV equations as explained in the two previous situations. As an example: to find the stand value/acre on the high-quality site necessary to earn 5 percent when the annual management-tax costs are $2/acre, land costs $35/acre, and the timber investment of $161/acre is compounded for 12 years, we used the two forms of the NFV equation. Summarizing the compounded values in the following equation we find:

$$\text{Total NFV} = \frac{\text{Timber}}{V_o(1+i)^n} + \frac{\text{Land}}{V_o(1+i)^n} + \frac{\text{Management–Tax}}{\frac{V_o(1+i-1)^n}{i}}$$

$$= \$161\ (1.79586) + \$35\ (1.79586) + \frac{\$2\ (.79586)}{.05}$$

$$= \$289.95 + \$62.86 + \$31.84$$

$$= \underline{\$384.65}$$

Other total NFV values (table 16) for the various interest rates were computed in a similar manner by substituting the appropriate values in the timber, land, and management-tax equations and finding their sum.

The computations show that it would be possible to earn over 6 percent compounded rate of interest on the high-quality site if annual management-tax costs were in the range of $1.00/acre and land costs around $15/acre. Under similar land and annual management-tax costs, we could expect the investment to earn around 3 percent on the low-quality site. Here again, the spread in percentage earnings between sites is a bit unrealistic because it is unlikely that land and tax costs would be the same for high-quality and low-quality sites.

SUMMARY AND DISCUSSION

The study reported here dealt with the results of applying selection silviculture to hardwood stands growing on two areas of different site quality — a high-quality site and a low-quality site. Thus the primary purpose of the study was to record and compare the biological responses and their economic significance attributable to site differences.

The results are strictly applicable only to the case studies described and should be applied with caution to stands, sites, cutting methods, and time periods that differ from those described.

The effects of site differences on biological response were expressed most clearly in species composition and in growth-rate differences. Sugar maple and beech were the two species most favored by selection silviculture on the high-quality site and beech and red maple were favored on the low-quality site. This is in contrast to clearcutting, which favors yellow-poplar and black cherry on high-quality sites and oaks on low-quality sites. Stand board-foot volume increased faster on the better site.

In summation of the biological responses; the results to date indicate that on both sites the imposition of selection cutting as practiced on the study areas will: (1) change the species composition toward a climax stand favoring shade-tolerant slower-growing trees, (2) drastically reduce the proportion of sawtimber in defective and low-grade wood, and (3) provide for adequate stand regeneration. The trends will be the same on both high- and low-quality sites.

In evaluating the economics of selection silviculture on high- and low-quality site sawtimber stands, we are concerned only with those biological responses that influence sawtimber log values. As expected, the responses that are significant biologically are also significant in determining stand values and value differences between sites. These responses are: (1) the trend in quality development, and (2) the trends in species composition.

As shown in the results, favorable quality development did occur on both sites during the study period. This was expressed by (1)

an increase of 18 to 25 percent in value due to the proportion of volume in log grades 1 and 2, and (2) a corresponding reduction in value due to reduction of volume in log grade 3 and lower quality classes.

Trends in species development on the two sites have both short-run and long-run significance in stand valuation based on present market preference and stumpage prices. In the short run, the practice of selective cutting on both sites has favored the development of the more desirable high-value species in the overstory.

In the immediate future, we would expect the stand values to continue increasing. However, the biological trends discussed above in species composition perpetuated by selection silviculture will encourage the development of less-preferred, lower-valued sawtimber tree species. This means that in the long run, if current market preference and relative stumpage prices prevail, the more valuable cherry, red oak, and yellow-poplar will be removed as it matures and will be replaced by such less-desirable species as beech, maple, and sweet birch now developing in the understory.

Further economic implications are evident from projecting current trends in stand composition, land values, and other factors as they affect timber values.

- In the long run, as stand-value development stabilizes and as timber values decrease because of the increasing predominance of lower-valued species, the timber investment will be unable to carry the land costs as well as it does at present.

- In the present land market, site quality does not greatly influence the cost of timberland. Many times, land with a high proportion of high-quality site will be marketed at the same price as less productive lower-site timberland. Other factors such as taxes, access, recreation potential, grazing potential, minerals, and location with respect to population centers have greater influence on timberland prices than timber site quality.

- The fact that these factors do have a significant influence on timberland values is important in making decisions on investments in growing timber. When and where the importance of these factors as an investment is increasing, the potential to invest in growing timber at a profit becomes less attractive in the long run and may be submarginal to other alternatives.

- Where a timberland owner has the option to invest in developing low- or high-quality-site timber stands, our results indicate that, per dollar invested, the high-quality-site — because of its faster growth and quality development — will produce timber values on 1 acre equivalent to 3 acres of low-quality-site timber. This ratio of 3:1 would hold true only when the cost of taxes and other costs remain equal.

- For the investor who seeks to buy timberland for the purpose of growing timber, the other-than-timber values play a major role in expected returns. As indicated above, site quality will not influence investment costs and expected returns as much as other timber-related investments. The potential investor must seek timberland where outside factors will not significantly influence the timber investment or where the influence of these factors can be minimized. The probability, that in the future, land can be purchased for the production of timber without the value influence of outside factors is small.

All-important in evaluating the effects of site quality on stand valuation is sound interpretation of the results of percentage and actual dollar value change. For the many economic measures used, we find similar percentage value changes over the period of study on both high- and low-quality sites. Thus, based on percentage value changes, we might erroneously conclude that investments in high- and low-quality sites produce similar economic gains. But, when we measure the value response in actual dollar change, we find the high-quality site increased $233/acre over the study period while the low-quality site increased $76/acre. Obviously, the value of

volume and quality development on the better site is superior to that found on the low-quality site.

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APPENDIX I

Table 1a.—Example of using "Q" to determine the distribution of trees by diameter class when the maximum diameter, desired basal area, and Q are given

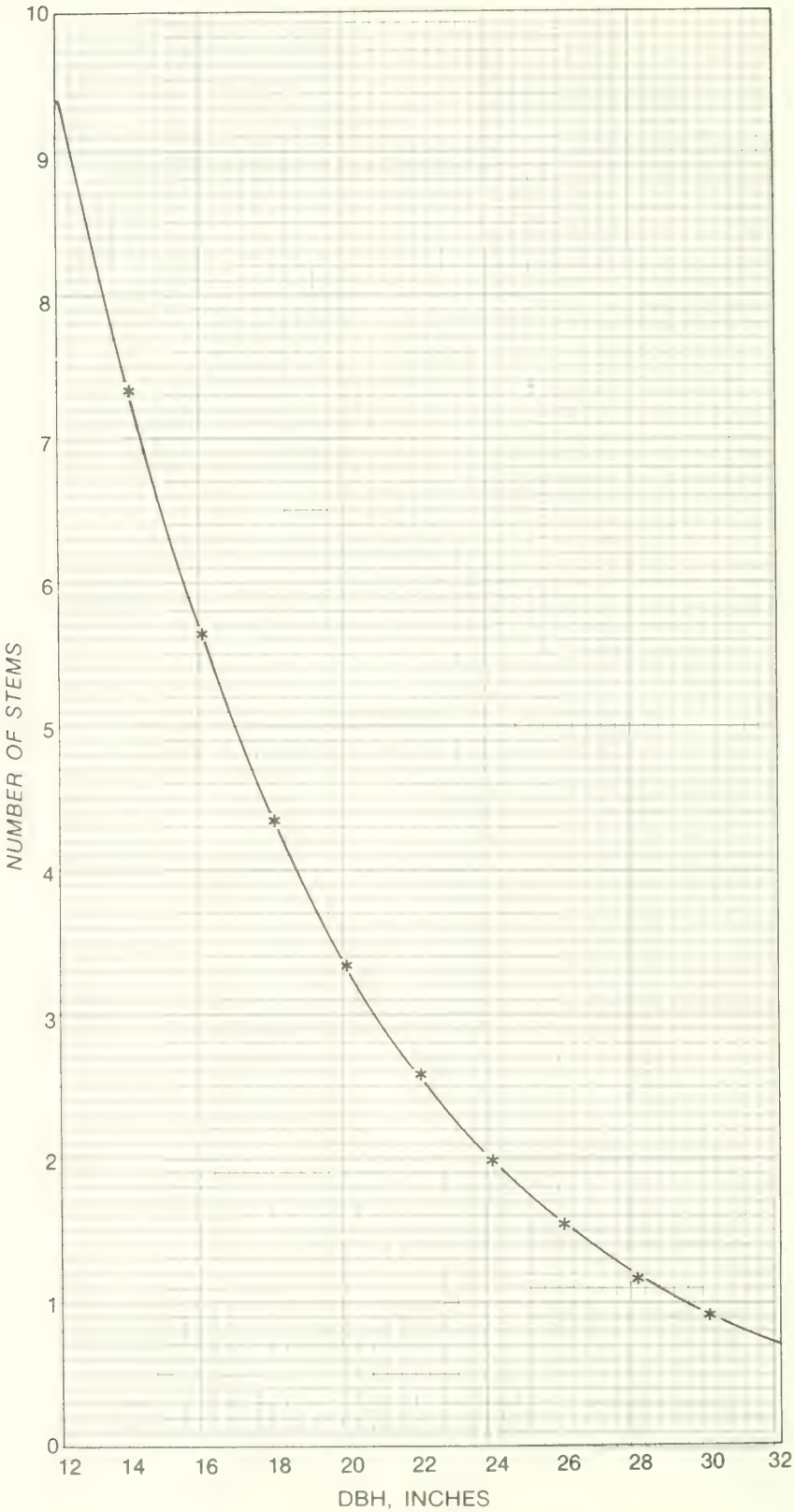
[Given: Q = 1.3; maximum dbh = 32 inches; basal area = 70 square feet]

Dbh class (inches)	Computations for Q distribution				
	Trees	Basal area per tree	Basal-area distribution	Adjusted number of trees	Basal area check
(1)	(2)	(3)	(4)	(5)	(6)
	No.	*Sq. ft.*	*Sq. ft.*	*No.*	*Sq. ft.*
12	13.82	0.785	10.85	9.53	7.48
14	10.63	1.069	11.36	7.33	7.84
16	8.18	1.396	11.42	5.64	7.87
18	6.29	1.767	11.11	4.34	7.67
20	4.84	2.182	10.56	3.34	7.29
22	3.72	2.640	9.82	2.57	6.78
24	2.86	3.142	8.99	1.97	6.19
26	2.20	3.687	8.11	1.52	5.60
28	1.69	4.276	7.23	1.17	5.00
30	1.30	4.909	6.38	0.90	4.42
32	1.00	5.585	5.59	0.69	3.85
Total	—	—	101.42	39.00	69.99

PROCEDURE FOR FINDING ADJUSTED NUMBER OF TREES

1. Set maximum dbh tree equal to 1.00 (32-inch dbh class). Multiply the given Q (1.3) by each preceding Q distribution factor to find number of trees for dbh class, e.g.:
   30-inch dbh class = 1.3x1.00 = 1.30
   28-inch dbh class = 1.3x1.30 = 1.69
   Record in column 2.
2. Find basal area per tree from table of area of circles. Record in column 3.
3. Multiply column 2 by column 3 to find basal-area distribution for each dbh class. Enter product in column 4; for example: 12-inch class = 13.82x.785 = 10.85. Find the sum of column 4 = 101.42.
4. Find factor by dividing the sum of column 4 into given basal area (70 square feet) = 70/101.42 = 0.69. Multiply number of trees, column 2 by the factor 0.69 to find adjusted number of trees. Record in column 5.
5. To check if adjusted distribution of number of trees renders the desired basal area, multiply column 3 by column 5 and record in column 6. The sum of this column should closely approximate the given basal area (70 square feet).

Figure 1.—Number of sawtimber trees per acre for a "Q" of 1.3 maximum tree dbh of 32 inches, and a basal area of 70 square feet.



APPENDIX II

Application of the Trial-and-error Method for Finding the Internal Rate of Return (IRR) for Site Quality Investments and Income Streams Shown in Table 12

The internal rate of return of an investment is that rate (percent) used to discount each term of an income stream to the year in which an investment is initiated and the results summed equal the beginning investment. To find the discount rate for our site-quality classes, we use the trial-and-error method and the IRR equation,

$$V_o = \frac{R_1}{(1+i)} + \frac{R_2}{(1+i)^2} + \ldots \frac{R_n}{(1+i)^n}$$

How do you proceed to find the correct discount rate to calculate an IRR? We have found that the graphic method provides a simple solution. We will use the high-quality-site data from table 12 to illustrate our method. The steps are as follows:

1. Substitute the values for V_o, R_1, R_2, and R_3 from table 12 in the IRR equation. Thus:

$$\$161.46 = \frac{\$13.72}{(1+i)} + \frac{\$50.32}{(1+i)^{10}} + \frac{\$394.13}{(1+i)^{12}}$$

2. Solve the discounting equation, using any reasonable rate. Find the value of $(1+i)$ for the selected rate from the interest tables for year 1, 10, and 12.

3. Compare the solution (we call this the NPW — *net present worth* of the income stream) with the initial investment. If the NPW is larger, select a higher rate and solve the equation, again using step 2.

4. Repeat the process, using a higher or lower rate to yield a result closer to the value of the initial investment.

5. Prepare a graph like that shown in figure 1. The X axis is labeled with a range of interest rates and the Y axis is labeled with a range of NPWs.

6. Draw the initial investment as a horizontal line.

7. Plot the NPWs previously calculated for the various discount rates.

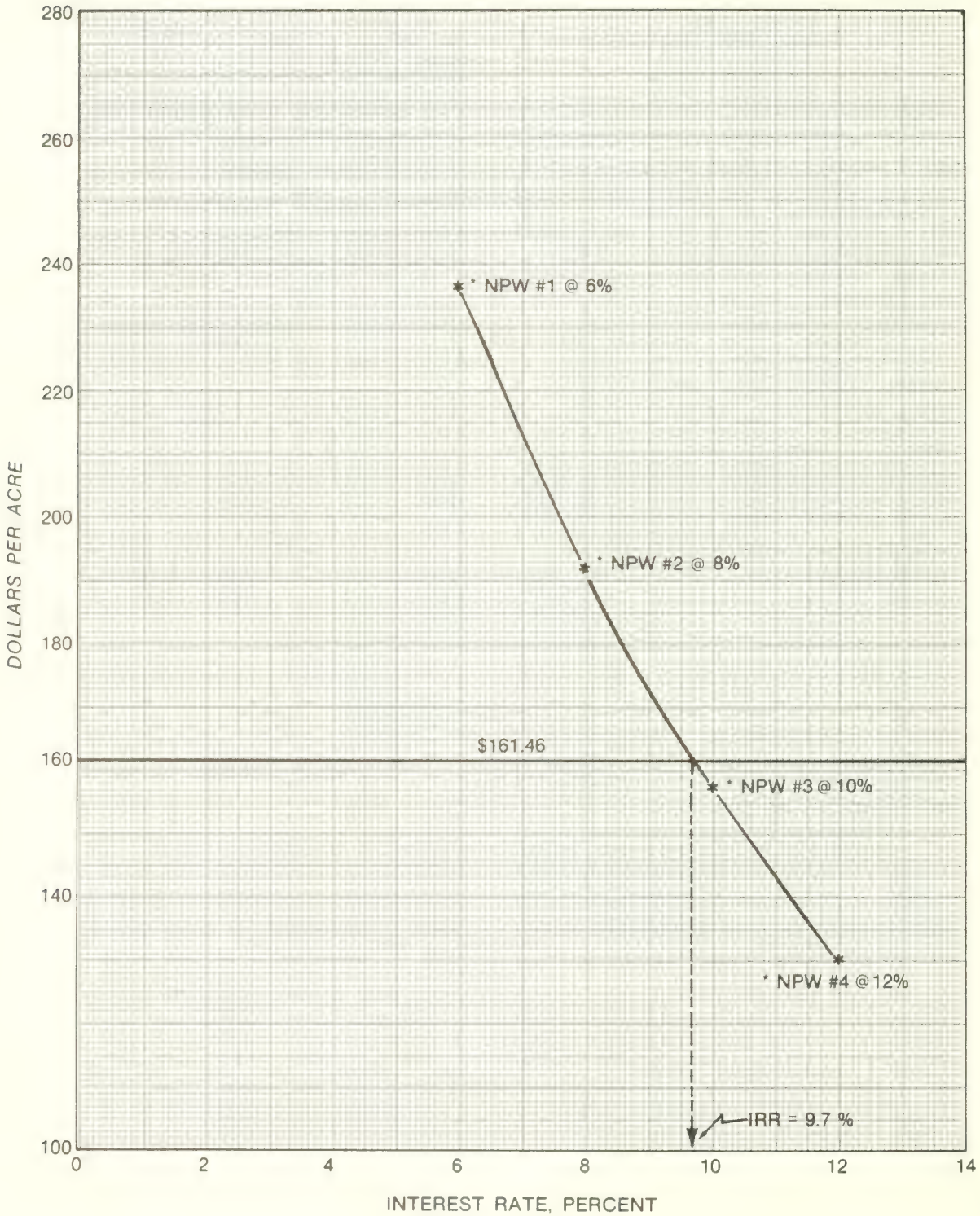
8. Calculate additional NPWs at different rates if you want additional plotting points to fill in the gaps.

9. When four or more points have been plotted around the horizontal line, connect with a smooth line.

10. From the intersection of the horizontal line and the curve, read vertically to the interest-rate scale. This is the interest rate that equates the income flow to the beginning investment or the IRR.

11. In figure 2 (appendix II), we used discount rates of 6, 8, 10, and 12 percent to plot the NPW curve. Using rates of 7, 9, and 11 would enable us to more accurately plot the curve and its point of intersection with the horizontal initial investment line.

Figure 2.—Graph for calculating internal rate of return (IRR) by the trial-and-error method. NPW is net present worth of the income stream.



APPENDIX III

Computing Net Future Value of an Investment When Intermittent Income is Reinvested

The flow of all net income attributable to an investment must logically be included in the net-future-value equation to measure the effectiveness or performance of the investment at some future point in time. References showing the application of net future value usually show application to periodic income and payments and costs for an investment. In practice, the net-future-value equation can be modified to account for any cost or income flow from the investment. In the illustration below we show how the equation is modified, using our site-quality information for the low-quality site presented in table 12.

To derive the true net future value, we use the initial value of the investment, \$63.68/acre, the first cut of \$14.65/acre, and the second cut of \$23.24/acre. We know that the original investment was made 12 years ago, the first cut 11 years ago; and it has been 2 years since the second cut was made. What is the net future value of our initial investment in the low-quality site after 12 years if we desire a 5-percent rate of interest on the investment and reinvest all net income from the investment at the same rate? Using a modification of the net-future-value equation where:

$V_n = V_o (1+i)^n - V_{o\,1} (1+i)^n - V_{o\,2} (1+i)^n$

when:

V_n = Net future value.
V_o = Beginning investment.
$V_{o\,1}$ = Net income of the first cut.
$V_{o\,2}$ = Net income of the second cut.
n = Period in years of the investment or income.
i = Rate of interest.

or:

$$\begin{aligned} V_n &= \$63.68\ (1+.05)^{12} - \$14.65\ (1+.05)^{11} - \$23.24\ (1+.05)^2 \\ &= 63.68\ (1.79586) - 14.65\ (1.71034) - 23.24\ (1.1025) \\ &= 114.36 - 25.06 - 25.62 \\ &= \$63.68 \end{aligned}$$

The net future value in our example is thus \$63.68/acre. Or our investment 12 years ago must equal \$63.68/acre to meet our goal of 5 percent on the initial investment and a like return on reinvested income from the investment. We note that the net future value would have been \$114.36/acre if we had not reinvested the income from the two cuts. Further, net future value measures the value of our investment at the stated interest rate. Our low-site value at the end of 12 years was \$140/acre or \$76.32/acre above our goal of \$63.68/acre. The undivided surplus or profit of \$76.32/acre is the amount in excess of the investment goal of 5-percent rate of interest on the forest investment.

APPENDIX IV

List of common and scientific names of species referred to in this study:

Ash, white	*Fraxinus americana* L.
Aspen, bigtooth	*Populus grandidentata* Michx.
Basswood	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Birch, yellow	*Betula alleghaniensis* Britton
Butternut	*Juglans cinerea* L.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin	*Prunus pennsylvanica* L. f.
Cucumbertree	*Magnolia acuminata* L.
Dogwood, flowering	*Cornus florida* L.
Elm, American	*Ulmus americana* L.
Elm, rock	*Ulmus thomasii* Sarg.
Elm, slippery	*Ulmus rubra* Muhl.
Gum, black	*Nyssa sylvatica* Marsh.
Hemlock, eastern	*Tsuga canadensis* (L.) Carr.
Hickory, bitternut	*Carya cordiformis* (Wangenh.) K. Koch
Hickory, shagbark	*Carya ovata* (Mill.) K. Koch
Hophornbeam, eastern	*Ostrya virginiana* (Mill.) K. Koch
Hornbeam, American	*Carpinus caroliniana* Walt.
Locust, black	*Robinia pseudoacacia* L.
Magnolia, Fraser	*Magnolia fraseri* Walt.
Maple, red	*Acer rubrum* L.
Maple, striped	*Acer pennsylvanicum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, chestnut	*Quercus prinus* L.
Oak, northern red	*Quercus rubra* L.
Oak, white	*Quercus alba* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Serviceberry, downy	*Amelanchier arborea* (Michx. f.) Fern.
Sourwood	*Oxydendrum arboreum* (L.) DC.
Yellow-poplar	*Liriodendron tulipifera* L.

McCauley, Orris D., and George R. Trimble, Jr.
1975. Site quality in Appalachian hardwoods: the biological and economic response under selection silviculture. NE. For. Exp. Stn., Upper Darby, Pa.
22 p., illus. (USDA For. Serv. Res. Pap. NE-312)

The percentage value response after 12 years of selective cutting on low- and high-quality sites amounted to a 119-percent increase on the low-quality site and 145 percent on the high-quality site. The low-quality site increased in value only $76/acre while the high-quality site increased $233/acre. Current trends in species composition indicate that selective cutting practices will change the species composition toward a climax stand favoring shade-tolerant, slower-growing, lower valued species.

221.41 : 228.6 : 652.9 : 651.9 : 646

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MANUSCRIPT RECEIVED FOR PUBLICATION 22 APRIL 1974

Estimating Starch Content in Roots of Deciduous Trees—A Visual Technique

by Philip M. Wargo

ABSTRACT

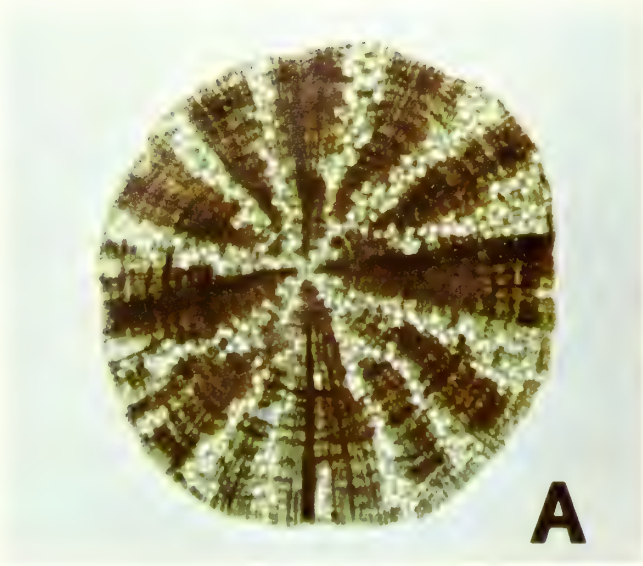
A visual technique for determining starch content in roots of forest trees, based on iodine-staining of starch granules, was compared with a chemical method. Although the chemical method was more precise, roots could be sorted with the visual method into groups that are probably biologically important. The visual technique is simple and can be adapted for use in the field.

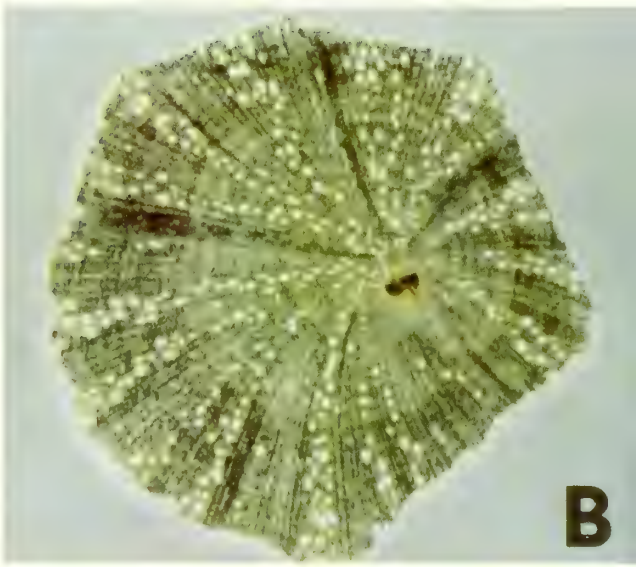
KNOWLEDGE OF TREE vigor is important in judging resistance of trees to disease and insect attack or predicting the ability of trees to tolerate stresses such as defoliation, drought, and air pollution *(Kozlowski 1969)*. Often tree vigor is determined after the fact; for example, trees that survive a pest attack or an adverse environmental condition are considered vigorous. Even vigor classes used to predict growth potential are based on the absence of disease and injury and the healthy appearance of the crown *(Trimble 1960, 1969)*. Vigor determination based on radial growth indicates how vigorous the tree has been, but does not necessarily show how vigorous it is now.

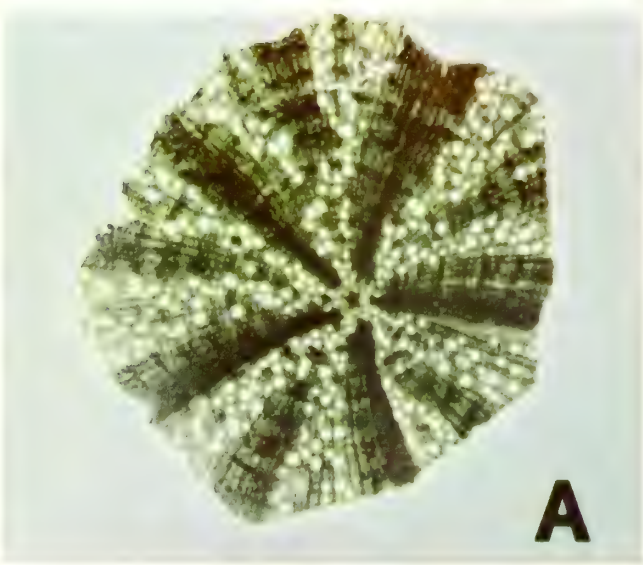
Starch content of the roots of deciduous trees may be a good index of tree vigor *(Wargo et al. 1972)*. Photosynthetic capacity is an indicator of the well-being of the tree; and starch, the major reserve carbohydrate in most deciduous trees, reflects photosynthetic capacity of the plant *(Kramer and Kozlowski 1960)*. Starch is stored in high concentrations in the roots *(Jones and Bradlee 1933, Murneek 1942, Wenger 1953, Wargo et al. 1972)*; it is sensitive to stresses such as defoliation *(Staley 1965, Parker and Houston 1971, Wargo et el. 1972)*, drought *(Parker 1970)*, and air pollution *(Miller et al. 1968)*; and changes can be observed within the same growing season when the stress is imposed *(Wargo et al. 1972)*.

If starch content of roots is a reliable index of tree vigor, its determination could be a valuable aid in decision-making for the practicing land manager. For this purpose an accurate and easy method of determining root starch is necessary. Several chemical extractions and analysis procedures are available for starch determination, but these require extensive training and laboratory equipment and cannot be adapted readily for use in the field.

Text continues on page 8.







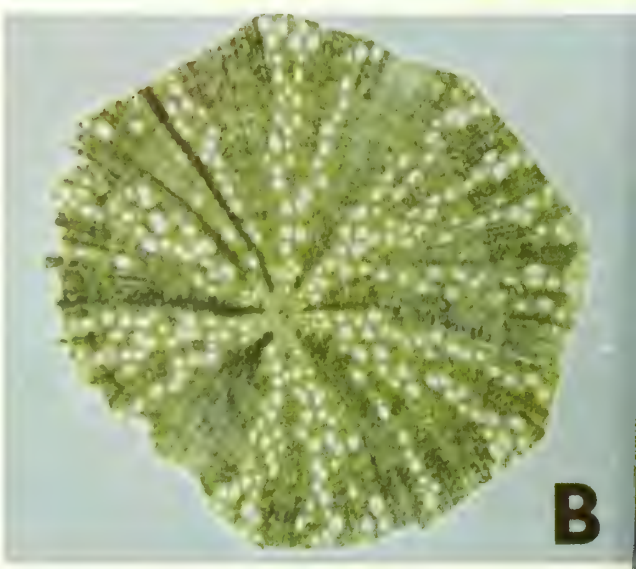
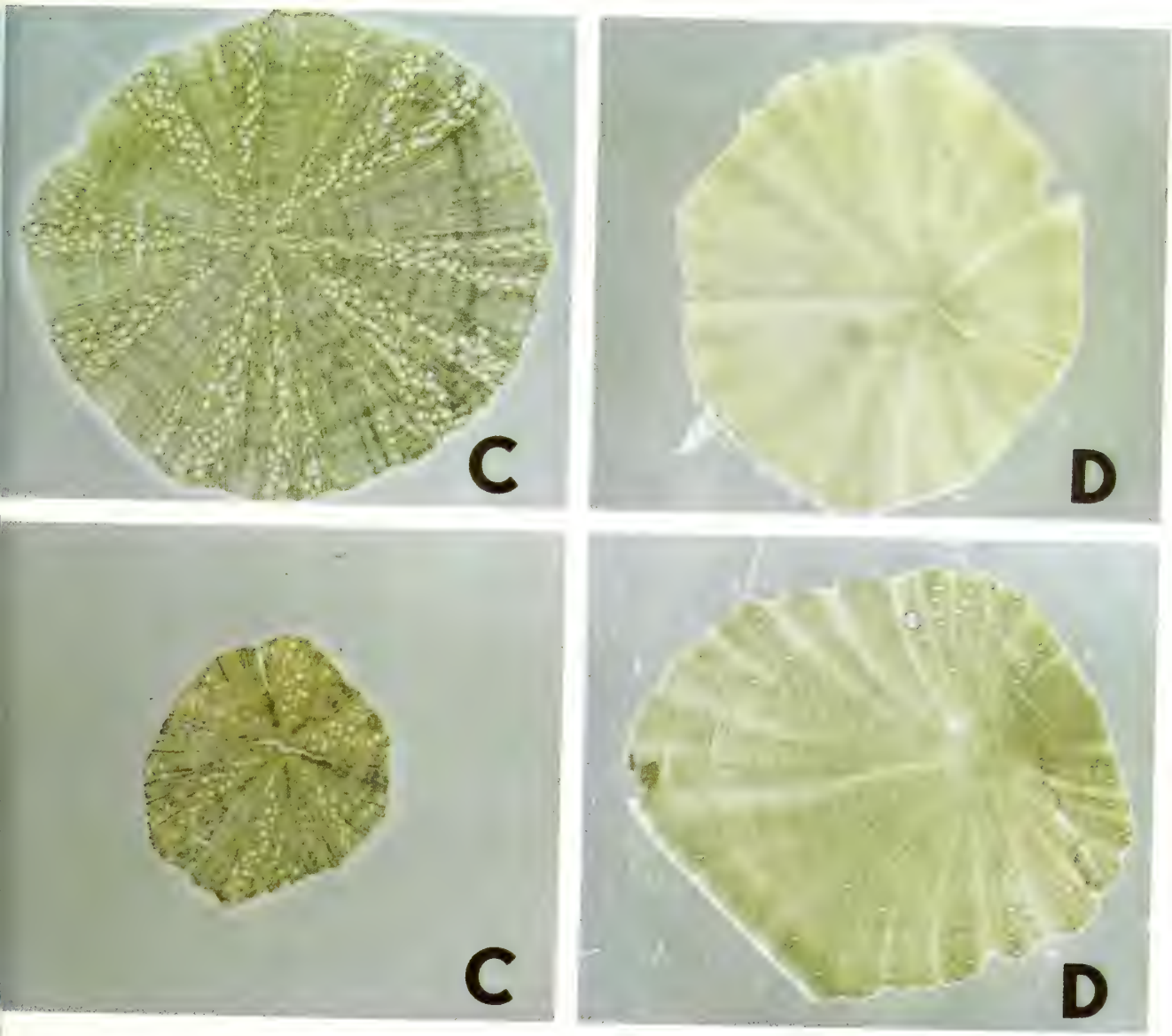


Figure 1.—Cross-sections of roots of red oak stained with I_2KI solution, showing several levels of starch content: A—high (15 to 30%), B—med-



ium (7 to 12%). C—low (3 to 6%). D—depleted (0 to 1%).
Magnification 7x.

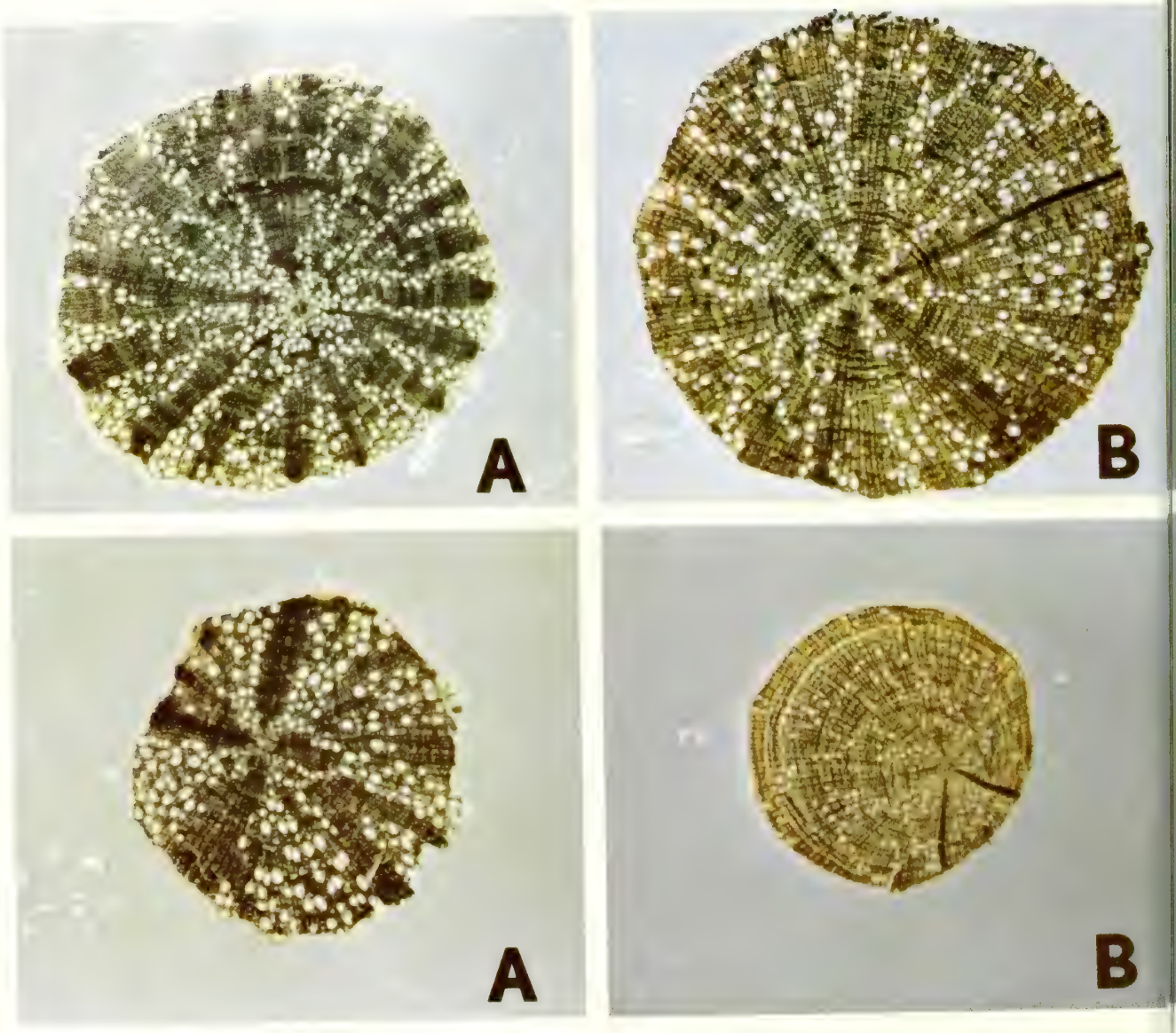
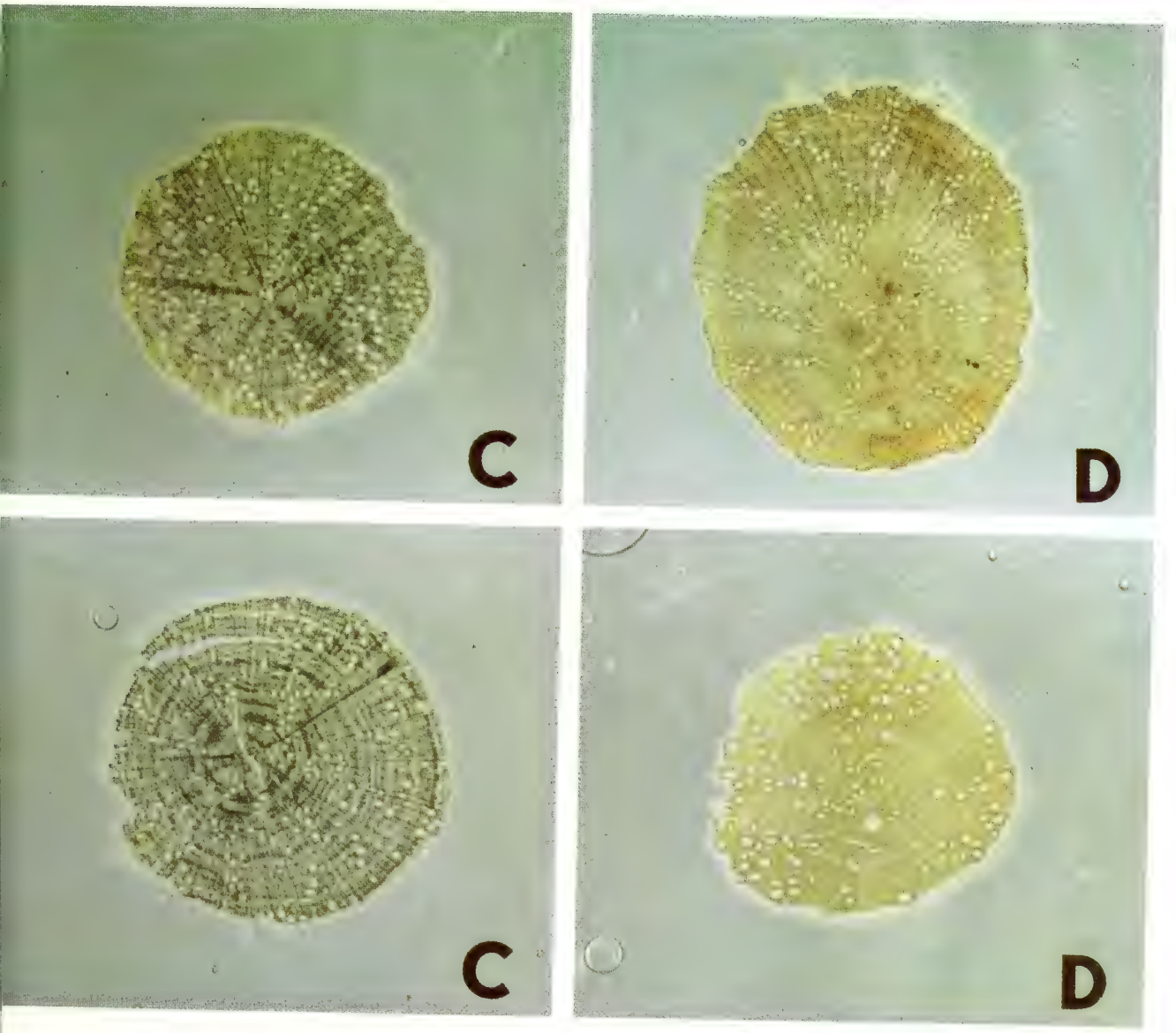


Figure 2.—Cross-sections of roots of white oak stained with I_2KI solution, showing several levels of starch content: A—high (15 to 30%), B—med-



ium (7 to 12%), C—low (3 to 6%), D—depleted (0 to 1%). Magnification 7x.

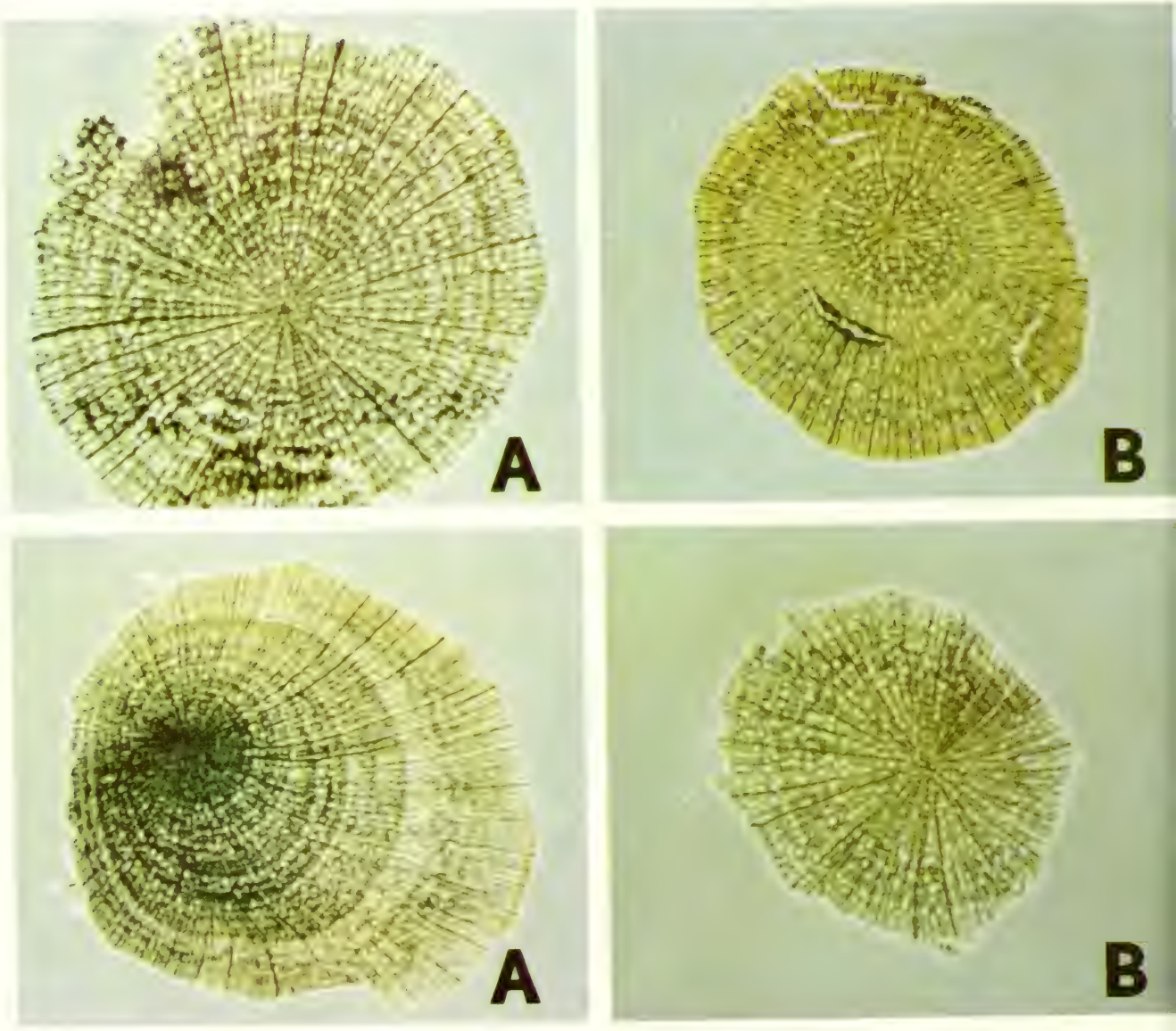
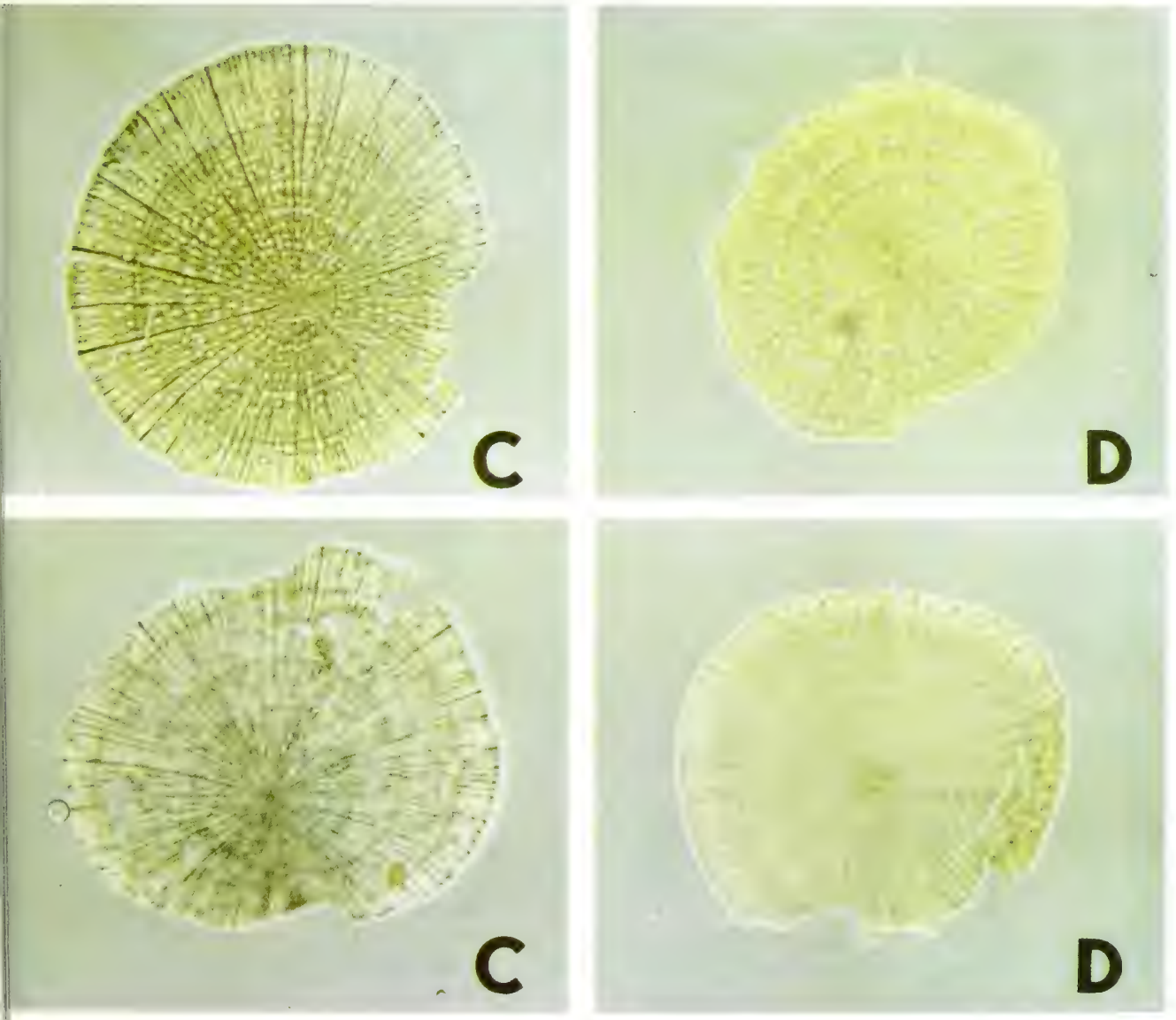


Figure 3.—Cross-sections of roots of sugar maple stained with I_2KI solution, showing several levels of starch content: A—high (12 to 25%), B—



medium (6 to 10%), C—low (2 to 5%), D—depleted (0 to 1%).
Magnification 7x.

Our study was made to evaluate a visual method for estimating levels of root starch in tree roots. A similar technique has been used to evaluate the effects of sheep grazing on root reserves in alfalfa *(Rather and Harrison 1939)*.

METHODS AND MATERIALS

Roots were collected before, during, and after the growing season, from red oak *(Quercus rubra* L.), black oak *(Q. velutina* Lam.), white oak *(Q. alba* L.), and sugar maple *(Acer saccharum* Marsh.). Trees of each species had been defoliated by hand during the growing season. This provided a range of starch levels for the test. Small sections of root were removed, placed in polyethylene bags, and kept in insulated bags with ordinary ice. Later, root pieces were cut in half; one-half was frozen and kept at —20 C until analyzed visually. The other half was debarked, dried, and ground in a Wiley mill to pass a 60-mesh screen and was analyzed chemically to determine starch content.

Starch was extracted chemically from the root tissue with perchloric acid according to the procedure of Hassid and Neufeld *(1964)*. Starch content, measured with the colorometric method described by Siminovitch et al. *(1953)*, was expressed as percent dry weight of tissue extracted.

Cross-sections of whole roots or portions of whole roots were stained with an iodine solution for the visual estimate of starch content. Root pieces were thawed rapidly, and cross-sections, approximately 100μ thick, were cut with a sliding microtome. The sections were kept moist at all times. At least two cross-sections were placed on a glass slide and flooded with I_2KI solution. The solution contained 15 g of KI and 3 g of crystalline I_2 in 1000 ml of distilled water. Excess solution was blotted, and fresh iodine solution was added. After 5 minutes the stain was blotted and the sections were rinsed twice with distilled water. Excess water was removed, glycerine was added, and a cover slip was placed over the sections. Staining results were recorded on Polaroid color film or 35-mm Ektachrome (Kodak Co.) color slides. Pictures were taken within 48 hours of staining because the stain faded after 72 hours.

RESULTS

Chemical Analysis

Chemically determined concentrations of starch ranged from 0 to 30% on a dry-weight basis. In general, the red oak group had the highest starch levels, followed closely by white oak and then sugar maple. The variation among subsamples of the same root tissue was small (table 1), and starch levels could be sorted into one of ten categories: 0%, 2±1%, 5±1%, 8±1%, 11±1%, 14±1%, 17±1%, 20±1%, 23±1%, and 25% and higher.

Table 1.—Variation of starch concentration in subsamples of the same root tissue, determined by chemical extraction and analysis.

[In percent dry weight]

Tree no.	Subsamples		
	1	2	3
1	7	7	7
2	0	0	0
3	3	3	3
4	19	20	20

Visual Analysis

With the visual technique, roots from all tree species could be separated easily into four categories of starch content: high, medium, low, and none or depleted (figs. 1 to 3). The low category could be separated further into very low and low within each species. In the oak groups, the corresponding chemically determined range of root starch in these categories was 15 to 30%, 7 to 12%, 3 to 6%, and 0 to 1%. For sugar maple the ranges were 12 to 25%, 6 to 10%, 2 to 5%, and 0 to 1%. Because of anatomical differences among species it was necessary to limit visual comparisons of starch content to within the same species or at least to related species such as red and black oak. Cross-sections 100 to 150 μ thick were suitable for staining and analysis, but sections 200 μ and thicker were not.

DISCUSSION

Chemical analysis of starch content permitted sorting of roots into more and narrower categories. With the visual technique, roots could be sorted easily into broader categories that are probably biologically important. Wargo et al. *(1972)* observed that defoliated trees had little or no starch in the roots, and that these levels reflected the adverse effects of stress on the trees. Unstressed trees, on the other hand, had high starch content in their roots. Drought also had a similar effect *(Parker 1970)*. Similar observations were made of alfalfa. Grazed alfalfa had lower reserves than ungrazed alfalfa, and starch content was important in winter survival of the plants *(Rather and Harrison 1939)*.

The visual technique is fairly simple and fast. It requires little equipment, and the procedure can be learned in a single day. The test can be done in a laboratory or, with some modification such as a hand microtome, in the field. The results can be read immediately or within 48 hours. The test is fairly accurate and repeatable, provided the staining solution is not more than 30 days old.

The visual technique offers a simple method for evaluating starch content in roots of deciduous trees. Such evaluation may be useful in determining tree vigor, in evaluating the effects of stress on trees, or in evaluating other methods and techniques of judging tree vigor.

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Acknowledgments: I thank Dr. Johnson Parker and Dr. David R. Houston, Northeastern Forest Experiment Station, Hamden, Connecticut, for their helpful advice, and Kenneth F. Aldrich, Harold G. Eno, and Roy L. Patton for their technical assistance.

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1975. **Estimating starch content in roots of deciduous trees — a visual technique.** NE. For. Exp. Stn., Upper Darby, Pa.
9 p., illus. (USDA Forest Serv. Res. Pap. NE-313)

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160.22—015.28:164.3:176.1

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Field Test with Helicopter Applications of Gardona Against Gypsy Moth in Pennsylvania

by Jack H. Barger
and Kenneth Helrich

USDA FOREST SERVICE RESEARCH PAPER NE-314
1975

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MANUSCRIPT RECEIVED FOR PUBLICATION 30 JULY 1974

Field Test with Helicopter Applications of Gardona Against Gypsy Moth in Pennsylvania

by Jack H. Barger
and Kenneth Helrich

ABSTRACT

In 1972, Gardona® WP was field tested against the gypsy moth, *Porthetria dispar* (L.), in Pennsylvania. Treatments of 1 gal/acre were applied by helicopter on six 100-acre plots, three at 1 pound AI/gal and three at 1.5 pound AI/gal. Check subplots of 0.1-acre were established throughout the area. Before and after spraying, evaluations were made by counting all visible egg masses and estimating defoliation to the nearest 10 percent. Kromekote cards and aluminum plates were used for qualitative and quantitative spray-deposit assessment. Leaves, soil, and water samples were collected at 1, 3, 6, 12, and 24 days after spraying for residue analysis. Analytical methods for determining residues are presented. Increases in both egg-mass density and percentage of defoliation were found after all treatments. Analysis showed no significant differences between the two doses nor between either of the two doses and the check. The kromekote cards and aluminum plates revealed minimal coverage (drops/cm^2) and deposits (gpa) at ground level. Data suggest that Gardona failed to affect the gypsy moth because (1) the study area had above-average precipitation, (2) the spray deposit and residue were highly variable, and (3) the residue dissipated rapidly from the leaves.

THE GYPSY MOTH, *Porthetria dispar* (L.), since its accidental introduction into the eastern United States, continues to spread and to defy a wide range of control actions. Increases in gypsy moth population to the west and south, resultant defoliation, and new spot infestations occur with increasing frequency.

Eradication and suppression of the gypsy moth, from 1890 to 1943, were attempted by applying creosote to egg masses, banding trees with burlap and sticky materials, spraying with lead arsenate *(Burgess 1930)*, and importing natural enemies from Europe and Japan *(Brown and Sheals 1944)*. From 1944 through 1957, DDT was used in control and eradication programs *(Nichols 1973)*. Use of the insecticide carbaryl (Sevin) as a substitute for DDT was begun in 1958 because of public concern over DDT residues.

Because carbaryl and trichlorofon (Dylox) are now used almost exclusively for gypsy moth control and containment programs, the need for other environmentally safe and nonpersistent insecticides became evident. Therefore the Animal Plant Health Inspection Service (APHIS) continued laboratory screening of named candidate toxicants against the gypsy moth in order to expand and create more chemical diversity in gypsy moth spray programs. Those toxicants that showed promise were to be field-tested by the Northeastern Forest Experiment Station's Forest Insect and Disease Laboratory to determine if the chemicals merited pilot-testing for operational feasibility by the Northeastern Area State and Private Forestry organization.

In early 1972, APHIS recommended that Gardona® (2-chloro-1-(2,4,5 trichlorophenyl) vinyl dimethyl phosphate) 75 percent WP be field-tested. Doane *(1964, 1966)* in earlier tests had shown Gardona[1] to be a promising toxicant against the gypsy moth when applied by backpack mistblower.

[1] Reg. U.S. Patent Office, by Shell Chemical Co., San Ramon, Cal. Mention of a proprietary product should not be taken as an endorsement by the U.S. Department of Agriculture, the Forest Service, or Rutgers University.

METHODS AND MATERIALS

Plot Layout

Six 100-acre plots were established in the Delaware State Forest near Marshall Creek, Pennsylvania. Five 0.1-acre (66X66-foot) subplots were randomly scattered in each 100-acre spray plot. All subplots were located at least 330 feet inside the plot boundary and were at least 198 feet apart. Fifteen 0.1-acre check subplots were scattered throughout the area, at least ¼ mile from any treated plot. Subplots were used to determine egg-mass densities and defoliation, and to serve as points of leaf and soil collections for residue analysis. Subplots were also used for sampling and determining the spray coverage and the amount of spray deposit reaching the forest floor under a closed canopy.

Plots were marked for spraying with bed sheets tied over 15- to 20-foot saplings nailed atop large corner trees. After spraying, all treated and check subplots were similarly marked with sheets to assist in identifying them on aerial photographs.

Treatments

Three plots were treated at the dose of 1 pound AI/gal and three plots at 1.5 pound AI/gal. No spray sticker was mixed with the formulation, but a measured quantity (0.1 percent w/v) of fluorescent tracer (Brilliant Sulfo Flavin FFA, General Analine and Film Corp.)[1] was included to aid in spray-deposit evaluation.

Four plots were sprayed on 2 June and two plots on 3 June, using a Bell 47G-2 helicopter equipped with 30 hollow-cone disk-type teejet nozzles having D4 tips and No. 25 cores on a 30-foot boom. Boom pressure was about 48 psi, and the flow rate was 11.5 gal/min. The helicopter was flown 35 feet above the canopy at 60 mph, was calibrated at 1 gal/acre, and had a swath width of 95 to 100 feet. The nozzle orifices where directed downward at 90° to the thrust line of the helicopter.

This equipment combination was chosen to produce an unconfirmed spray atomization of 250 to 300 μ in volume median diameter (vmd). (Volume median diameter is the drop diameter that divides the spray volume in half; 50 percent of the spray volume is in drops of larger diameter and 50 percent in drops of smaller diameter.)

By 2 June, leaves were at least 50 percent expanded, and most gypsy moth larvae were in their second stadium. At each spraying, wind speeds were 3 mph or less. On 2 June, 4.5 hours after spraying, 0.28 inch of rain fell in the area. Also on 3 June, 8 hours after spraying, 0.08 inch of rain fell. Rain fell on 26 days, totaling 8.85 inches for June, which was 5.02 inches above normal.

Egg-Mass Counts

Before and after spraying, estimates were made of egg-mass densities by counting all visible egg masses in each 0.1-acre subplot, using binoculars when necessary. No attempt was made to count egg masses under rocks and debris. The mean number of egg masses in the five subplots per treatment plot was used to estimate number of egg masses per acre.

Defoliation Estimates

All trees of the white and red oak groups having a dbh of 2 inches or greater were number-tagged in each 0.1-acre subplot. The average number of preferred host trees in the treated and check subplots was 22, range 3 to 34. Defoliation estimates were made in increments of 10 percent on all numbered trees. Before-spraying foliage estimates were begun the first day of spraying (2 June) and were completed by 5 June. After-spraying foliage estimates were begun on 26 July and were completed on 1 August. The same individual made both before and after foliage estimates to minimize subjective error.

Spray-Deposit Assessment

Kromekote cards and aluminum plates were placed in each 0.1-acre subplot in all treated plots for qualitative and quantitative spray-deposit assessment. The forest canopy

in all subplots was judged to be the closed type. The kromekote cards, eight per subplot, were placed along two sides of each subplot border in the direction of the flight path for determining the number of spray drops reaching the forest floor, thus providing an index of deposit coverage. Four aluminum plates were placed in each subplot to sample spray deposit reaching the forest floor for the quantitative determinations of deposit in terms of gallons per acre (gpa). Cards and plates were supported by wire card holders *(Maksymiuk 1959)*. Cards and plates were collected for assessment immediately after spraying.

The spray drops on the kromekote cards were counted under a dissecting microscope with a UV illuminator. The quality of spray deposit was determined by taking the mean number of drops from 40 cards for each treatment combination, expressed as number of drops/cm^2.

The quantity of spray deposit was determined by washing the aluminum plates with 10 ml of 95-percent ethanol. The concentration of fluorescent Brilliant Sulfo Flavin FFA dye was determined with a spectrofluorometer. The deposit removed from the aluminum plates was converted to gpa from the actual concentration of dye in the formulation.

Sampling and Preparation for Residue Analysis

Available analytical methods were combined and modified for more efficient chemical assay of residues *(Shell 1967, 1970; Beroza and Bowman 1966)*.

Leaf and soil samples were collected from each treatment subplot and from 6 of the 15 check subplots on 3, 5, 8, 14, and 26 June. Separate leaf samples were taken from both upper and lower sections of the same tree crown. Each sample was a composite from the four tree quadrants. Water was sampled at nine locations in and adjacent to the various plots. Soil samples were taken at random points within the subplots.

Leaf samples were frozen, chopped in a Hobart food chopper, and refrozen to await analysis. Soil samples were frozen for storage, then thawed and screened to remove leaves, roots, and stones before extraction. Water samples were refrigerated until analyzed.

Extraction from Leaves

For each assay, a 100-g sample of chopped frozen leaves was placed in a mason jar, 400 ml of 1:3 hexane-isopropanol solution was added, and the mixture was blended for 3 minutes on a high-speed blender. The sample was filtered directly into a 500-ml graduated cylinder through a plug of glass wool in a powder funnel.

The solution was poured into a 500-ml separatory funnel containing 50 ml of distilled water and shaken. The wash was repeated six times, using 100 ml of distilled water for each wash. The wash water was discarded. The emulsion formed was broken by stirring with a glass rod. The hexane extract was stored in glass bottles in the refrigerator over 5 g of sodium sulfate. In the case of very low residue values (<0.10 ppm), 50 ml of the solution were concentrated to 10 ml by using a flash evaporator with water bath at 40°C.

Extraction from Soil

Each 40 g of frozen and sifted soil sample was placed in a 500-ml Erlenmeyer flask and slurried with 25 ml of distilled water. To the flask 200 ml of acetonitrile were added, and the flask was shaken for 1 hour on a Burrell wrist-action shaker. The solution was filtered through fluted Whatman No. 1 filter paper into a 100-ml graduated cylinder, and 75 ml were poured into a 250-ml separatory funnel containing 100 ml of distilled water. Gardona was extracted by using three aliquots hexane: 60 ml, 40 ml, and 40 ml respectively. Each time, the acetonitrile-water layer was removed into the beaker, and the hexane was run into a 250-ml Erlenmeyer flask. The acetonitrile-water was returned to the separatory funnel for the next extraction. When the extractions were completed, the hexane solution was dried over 15 to 20 g sodium sulfate for at least 15 minutes. The extract was decanted into a clean Erlenmeyer

flask and condensed to 1 ml, using a concentrating tube and flash evaporator with water bath at 40°C.

Extraction from Water

An 800-ml water sample was saturated with sodium chloride (about 290 g) in a 1-liter Erlenmeyer flask. The saturated solution was poured into a separatory funnel and shaken for 3 minutes with 800 ml hexane. The hexane layer was removed to a 1-liter flask and dried over 50 g sodium sulfate. The extraction was repeated with the same 800-ml water sample. The extracts were combined and condensed to 1 ml by flash evaporation with water bath at 40°C.

Gas Chromatography Measurements

Instrument: Micro Tek 220; detector: flame photometric; inlet temp: 220°C; column temp: 220°C; detector temp: 215°C; column: 36 X ¼ inch O.D. aluminum; packing: 5 percent OV 101 on acid washed chromosorb W; nitrogen: 100 ml/min; hydrogen: 100; oxygen: 25; injection: 5 μl.

RESULTS AND DISCUSSION

Increases in egg-mass densities were found after every treatment combination (table 1). Generally, those plots having the lowest initial egg-mass density had the highest percentage increase. Analysis (ANOVA) showed no significant difference in egg-mass counts between the two levels of treatment; nor was there any significant difference between any treatment combination and the check.

All treatment combinations showed increases in average percentage of defoliation. Those treatment combinations having higher before-spraying egg-mass densities generally had greater after-spraying defoliation. Although there is numerical evidence of some foliage protection, there was no significant difference in after-spraying defoliation between the two doses and no significant difference between either of the two doses and the check.

Quantitative and qualitative data obtained from the aluminum plates and kromekote cards show tremendous variation in both gpa and number of spray drops/cm² at ground level (table 2). The overall range of deposit on aluminum plates was 0.0001 to 0.066 gpa. The mean gpa deposit for 1.0 pound AI/gal was 0.00507 and for 1.5 pound AI/gal was 0.01592.

No kromekote card in any subplot had a droplet density range of 15 or more drops/cm². Few cards fell in the medium range of 5 to 15 drops/cm². More than 90 percent of all cards were in the light range—five or fewer drops/cm². The mean number of drops/cm² for 1.0 and 1.5 pound AI/gal was 2.41 and 1.75 respectively.

There was great variation in residue among subplots within a given treatment combination (table 3). For example, residues 1 day after treatment ranged from

Table 1.—Mean estimates, before- and after-spraying, of egg masses/acre and defoliation, by plot and treatment

Treatment (lb AI/acre)	Average egg masses/acre			Average defoliation		
	Before	After	Net increase	Before	After	Net increase
	No.	*No.*	*No.*	*Pct.*	*Pct.*	*Pct.*
1.0	320	2,812	2,492	6	19	13
1.0	368	2,070	1,702	8	18	10
1.0	1,976	3,758	1,782	7	29	22
Mean	956	2,935	1,979	7	22	15
1.5	732	2,586	1,854	16	25	9
1.5	844	4,276	3,432	10	27	17
1.5	3,244	5,114	1,870	8	32	24
Mean	1,607	3,992	2,385	11	28	17
None	1,241	5,541	4,300	8	34	26

Table 2.—Quantitative and qualitative spray-deposit assessment of Gardona 75 percent WP applied by helicopter

Treatment (lb AI/acre)	Aluminum plate, deposit		Kromekote cards, drops/cm²	
	Average	Range	Average	Range
	gpa	*gpa*	*No.*	*No.*
1.0	0.00092	0.0007 - 0.0013	3.13	1.59 - 6.09
1.0	.00842	.0004 - .0251	2.27	.59 - 4.44
1.0	.00587	.0007 - .0250	1.82	.50 - 3.50
Mean	.00507	—	2.41	—
1.5	.02784	.0069 - .0573	3.03	2.00 - 5.19
1.5	.00135	.0001 - .0073	.70	.31 - 1.00
1.5	.01857	.0031 - .0660	1.51	.97 - 2.34
Mean	.01592	—	1.75	—

Table 3.—Mean Gardona residues on leaves, in soil, and in water, assayed by gas chromatography
[Data pooled to plots and treatments; Rutgers University, 1972]

Treatment (lb AI/acre)	Leaves (days after treatment)					Soil (days after treatment)					Water (days after treatment)		
	1	3	6	12	24	1	3	6	12	24	1	3	6
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppb*	*ppb*	*ppb*
1.0	12.35	2.85	1.50	0.45	0.08	0.27	0.16	0.14	0.36	0.16	—	—	—
1.0	14.19	3.06	1.52	.76	.08	.05	.26	.28	.28	.14	0.4	6.3	0.2
1.0	18.94	1.06	1.40	.65	.03	.12	.14	.25	.13	.07	2.8	1.1	.4
Mean	15.16[1]	2.32	1.47	.62	.06	.15[2]	.20	.22	.26	.12	1.6[3]	3.7	.3
1.5	25.70	3.78	2.30	.80	.11	.23	1.52	.78	.37	.46	—	—	—
1.5	17.00	4.15	2.30	.86	.05	.18	.31	.34	.20	.15	3.1	.8	.1
1.5	24.30	2.78	1.98	.80	.05	.43	1.57	.28	.27	.23	1.8	1.2	.2
Mean	22.33	3.57	2.19	.82	.07	.28	1.13	.47	.28	.28	2.5	1.0	.2
None	.11[4]	.13	.03	.04	.0	.02[5]	.04	.01	.07	.0	.1[6]	.2	.1

[1] Mean based on 30 assays; [2] 15 assays; [3] 2 assays; [4] 12 assays; [5] 6 assays; [6] 3 assays.

0.09 to 100.7 ppm on leaves. At 3 days after treatment the range was not nearly as great: 0.09 to 14.7 ppm. Residues on leaves continued to dissipate rapidly, and at 24 days after treatment 10 of the 30 subplots had no detectable residues.

Although the leaf assay means of the two doses at 1, 3, and 6 days after treatment showed a difference of about 50 percent, corresponding to the difference in pound AI/gal applied, and in the expected direction, the variation in residue was so large that an analysis to determine differences between the two doses could not be established. Furthermore, in laboratory tests conducted by APHIS, second-instar gypsy moth larvae were fed an artificial diet fortified with levels of Gardona ranging from 63 to 1,000 ppm; and at 63, 167, and 200 ppm, which corresponded somewhat to ppm residues detected on leaves, larval mortality was <10 percent after 72 hours *(McLane 1973)*.

Residues in soil did not exceed 2.9 ppm for any sample at any time. For water, the highest level detected was 6.3 ppb; and by 6 days after treatment, residues had dissipated to <0.4 ppb.

The failure of Gardona to either protect foliage or to reduce egg-mass density may have resulted from one or any combination of the following: (1) above-average rainfall in the study area (June 8.85 inches, July 5.06 inches); (2) insufficient and highly variable spray deposit, demonstrated by data from the qualitative and quantitative spray-deposit assessment; and (3) rapid dissipation of residues from leaves, confirmed by the chemical assay.

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ACKNOWLEDGMENTS

We are grateful to William F. Carey, Rutgers University, for conducting the residue-analysis sampling program; to Carl M. Monroe, Shell Development Company, and Shell Chemical Company, Division of Shell Oil Company, for their technical and in part financial support; to Edwin A. Throckmorton, USDA Forest Service, for conducting the defoliation estimates and assisting in egg-mass counts; and to Bohdan Maksymiuk, John Neisess, and Michael J. Haskett, USDA, Corvallis, Oregon, for determining spray quality and quantity.

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Gardona was evaluated as a candidate toxicant for gypsy moth suppression in a field test. Egg-mass counts and defoliation estimates were made before and after spraying. Qualitative and quantitative spray-deposit assessments were conducted. A chemical assay of leaves, soil, and water was made to determine residues. Data suggest that Gardona failed to affect the gypsy moth.

414.4:453--145.7 x 18.77 *Porthetria dispar* L.--045

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T-H-A-T-S

- TIMBER
- HARVESTING
- AND
- TRANSPORT
- SIMULATOR

WITH SUBROUTINES FOR APPALACHIAN LOGGING

BY A. JEFF MARTIN

USDA FOREST SERVICE RESEARCH PAPER NE-316
1975

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MANUSCRIPT RECEIVED FOR PUBLICATION 13 MAY 1974

ABSTRACT

A computer program for simulating harvesting operations is presented. Written in FORTRAN IV, the program contains subroutines that were developed for Appalachian logging conditions. However, with appropriate modifications, the simulator would be applicable for most logging operations and locations. The details of model development and its methodology are presented, along with generalized flow charts. Each component of the simulator (felling, skidding, etc.) is discussed individually. Input requirements and program output are presented in detail with the aid of information for an example logging operation.

T-H-A-T-S

-TIMBER
-HARVESTING
-AND
-TRANSPORT
-SIMULATOR

WITH SUBROUTINES FOR APPALACHIAN LOGGING

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CONTEMPORARY TIMBER harvesting is a complex enterprise requiring many managerial decisions. In addition to the age-old concerns for profit margin, timber supply, and labor, the manager today faces new challenges on an increasingly broadened front. Machinery costs are higher than ever, and a proliferation of designs makes purchasing decisions more and more difficult. Greater attention to the environmental aspects of logging demands sharpened managerial skills.

Consequently, logging operators should use all the modern decision-making tools that they can. One of these, computer simulation, is a low-cost means of assessing the outcomes of decisions before they are actually carried out. In this report, a computer program for simulating the harvesting process is described in detail, along with instructions for its use. We call this program T-H-A-T-S, for Timber-Harvesting-And-Transport-Simulation.

Computer usage is no longer a luxury enjoyed by only the big companies. Today the computer is fast becoming a necessity; and even to the smaller operators, it is no longer a financial burden. With the advent of remote terminals, linked to large computers, access is available to virtually anyone.

Of course, simulation should not be thought of as a panacea; it is only as good as the quality of data used with it. Simulation is not a replacement for sound judgment and experience; rather, it is a managerial supplement for today's complex decision-making.

USES OF T-H-A-T-S

In its present form, T-H-A-T-S is best suited for investigations related to existing logging operations. We have quantified some of the many relationships contained within a logging system, but the job is not complete. Also, we have used data exclusively from the Appalachian Region.

Input for T-H-A-T-S includes time and motion data appropriate to the system being studied. For those functions in which operating or delay time has not been related quantitatively to system or stand parameters, the input consists of expected values (and their standard deviations). Therefore, to evaluate proposed systems, or to estimate costs and production for proposed sales, considerable care must be exercised. Data obtained from other sales could be used initially; however, these should be verified as soon as possible by observing the operation under the new conditions. Updated information should then be used in the simulation studies.

The basic simulator should be applicable for virtually any logging system. However, for areas outside the Appalachian Region, certain modifications would undoubtedly be needed. Most of these changes would involve only the subroutines, because the main program handles the logic of harvesting, utilizing data from the subroutines. Consequently, even such exotic systems as balloon logging can be analyzed by T-H-A-T-S if appropriate data and relationships are available.

As the adequacy of data improves, we will be better equipped for determining the relationships between system variables. This will greatly improve the simulator's capability for prediction and will permit better analyses of proposed systems and contemplated timber sales.

The uses of T-H-A-T-S are about as varied as the investigator's imagination. Some of the more obvious uses are listed below (*Martin 1973*):

Cost comparisons.—The existing system's economic picture can be compared to what would result if more men or machines were added, or if certain parts were modified or even eliminated. Many possibilities can be examined at a fraction of the cost involved with field-testing.

Production comparisons.—These can be made both with the system and its possible modifications, and between the system components.

Time analysis.—How is the operating and delay time distributed? How are operating times distributed within a cycle? What is the variability of the time factors?

Trouble-shooting.—Locating the limiting factors in the system. Why doesn't actual production keep pace with potential?

Predicting sale parameters.—Daily production and costs; total production and costs; time required for logging the sale; when various machines can be expected to be available for other areas, etc.

STRUCTURE OF T-H-A-T-S

T-H-A-T-S consists of a main program and 23 subroutines. The main program is composed of eight components (felling, bunching, skidding, bucking, loading, hauling, roadbuilding, and cost accounting) and a "clock." The clock records the passage of time for "real-world" similarity (fig. 1).

Each component utilizes one or more subroutines, and some subroutines are used by more than one component. The subroutines and where they are used will be explained in greater detail.

METHODOLOGY OF T-H-A-T-S

There are two broad classes of simulation models: those that are continuous and those that are discrete. Briefly, the continuous model updates the clock by some fixed time increment, and then proceeds through each step of the system before advancing the clock again. The discrete model first examines all components of the system and then advances the clock to the time when the next event will occur.

T-H-A-T-S is actually a meld of both concepts. It is continuous in the sense that time is incremented minute by minute; and it is discrete in the sense that only a few steps of the system are encountered during each increment. This is accomplished by a series of status checks that cause the system to bypass components that are performing a task. Only when the task has been completed will the system return to the component so that values (time, volume, etc.) for the next task can be generated. This approach causes the computer program to leapfrog through the system and hence greatly reduces the computer time and charges (see appendix C).

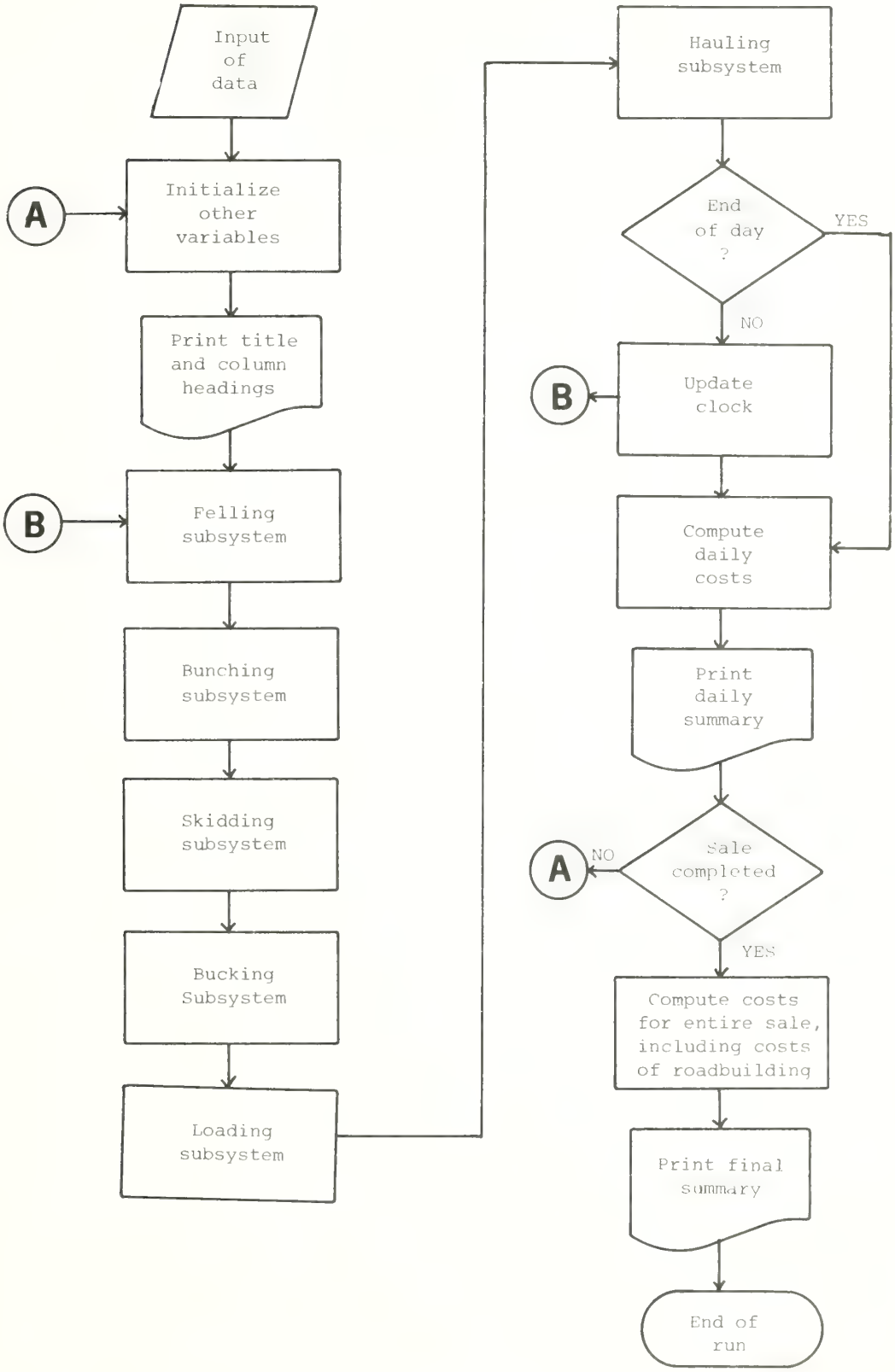
Control of the leapfrogging is maintained by a set of surplus-time variables, one for each system component. For example, if 6 minutes have been generated as the time required for a skidder to travel from landing to the felling area, then the surplus time for this skidder would be set initially at 6 minutes. Then, each time the clock is incremented by 1 minute, the surplus time would be decremented by 1 minute. When surplus time equals zero, it will be time to start another task—in this case, hooking up the logs.

The simulated time for performing each task is generated in one of two ways. Either the time is based on an average value obtained from the operation being studied and is part of the input data; or it is estimated by means of an equation obtained from regression analysis of data collected on several operations. Most of the subroutines are designed so that either option may be used. However, the equations were developed from data collected in the Appalachian Region, hence their use outside this area is not recommended unless they are checked for local accuracy.

The average or predicted time is then combined with the appropriate standard deviation or standard error to generate a random variable (the simulated time), using either a normal or lognormal generator (see appendix B). The simulated time for each task within each system component is generated separately and independently for both the operating and delay time. The total cycle time for a component is the sum of all individual time elements. For example, suppose the following times were generated for a felling cycle:

Task	*Operating time (min.)*	*Delay time (min.)*
Walking between trees	2	2
Felling	3	0
Limbing and topping	2	1
Bucking	0	0
Total	7	3

Figure 1.—Flow chart showing the components and major operations of T-H-A-T-S.



Total cycle time in this instance is 10 minutes.

The generation of operating time for a particular task requires only an average value (input or predicted by an equation) and its standard error; generating delay times requires the frequency of occurrence as well, with frequency defined as follows:

$$f_{ij} = E(N_{ij})/100$$

where f_{ij} = Frequency of delay for the ith task in component j.

$E(N_{ij})$ = Expected number of delays per 100 cycles for the ith task in component j.

Delay frequencies, averages, and standard deviations must be obtained from the operation being studied or, if care is used, from past operations.

In addition to generated delay times, there are various points in the system at which the interaction of two or more components may give rise to additional delays. For example, delay results when one truck must wait at the landing until another truck finishes loading. Or both trucks and the loader may have to wait until a skidder brings more logs (or trees) to the landing.

All the generated operating times are in integer minutes equal to or greater than 1. All delay times generated by T-H-A-T-S are integer values equal to or greater than zero.

When a cycle has been completed, all variables pertaining to that cycle are reset at zero. However, before this, all the values are added to cumulative arrays so that daily costs, times, and production can be summarized.

There are several queuing points within the system to accumulate logs or trees until they are moved to another point. There are queues for logs (or trees) waiting to be bunched, waiting to be skidded, waiting to be bucked (if trees are bucked at the landing), and waiting to be loaded. Another queue keeps track of trucks waiting at the landing and "releases" them for loading on a first-in-first-out basis.

T-H-A-T-S also provides a half-hour lunch break during each day. Of course, this can be deleted or changed to suit the program user (see statements 910 + 8, 919, and 919 + 1 in the program listing). Copies of the program listing, input instructions, sample output, etc. are available on request from the author.

The system shuts down at the end of each day in a staggered manner. In other words, each machine, man, or crew finishes the day near the specified quitting time; but it may be sooner for some and later for others. To better understand this procedure, let's define A = quitting time—10 minutes. The program calls for all components (except hauling) to finish a cycle if it was started before A: but not to begin another cycle after A. For example, if a felling crew starts to fell a tree at 4:45 p.m. and the cycle time is 10 minutes, the crew will quit at 4:55 p.m. (if the nominal quitting time is 5:00 p.m.).

The quitting rule for hauling is a bit more complex because an algorithm is used to simulate the driver's decision-making as to whether he thinks another trip can be completed in the time remaining. The estimated time for the next trip is assumed to be equal to the time used for the last trip less one-half of its delay time. If this estimated time is less than the time remaining in the day (which is based on the specified quitting time plus 1 hour), the driver will return to the landing. Of course, these assumptions may be changed by the user (statements 845 + 2 and 850 + 1). The program also makes provision for a truck waiting overnight at the landing, either empty or partially loaded. This would occur if the loader should quit before a truck arrives or if the log supply should run out before a truck is loaded at quitting time.

There are also checks for each system component to determine when they have completed their work on the current timber sale. When the fellers have cut all of the available volume (number of acres times volume per acre), they are finished. When the skidders have moved this volume to the landing, they are finished; and so forth for all components. It is possible that not enough volume remains at the end of a day to warrant having all machines in a component working on the next day. For example, suppose a system has two skidders in operation, but on the day when the felling crews finish cutting, it seems that only one skidder will be needed to finish up on the next day. The program is designed to

make and implement these decisions for all of the components.

On the following pages, the components are discussed in some detail, and a flow chart is provided for each. The flow charts depict the workings of the simulator, but do not necessarily conform to the way in which the program is written-notably the bucking, loading, and hauling portions. The program listing shows that these three components are quite interwoven with respect to the statements. The flow charts separate them so that the operation is easier to understand.

FELLING COMPONENT

The felling component comprises four separate tasks: walking between trees, felling the trees, limbing and topping, and bucking (optional). Completing all four tasks constitutes one felling cycle, and generally one tree has been prepared for transporting to the landing. When a cycle is over, the next one is begun (fig. 2). This process continues until it is time to quit for the day, whereupon a daily summary of operating and delay times, costs, and production is prepared for each felling crew.

Certain subroutines are required for each task. Subroutine WALK requires an average value (average walking time between trees) as input. Subroutines FELL and LIMB permit the use of an average value (as input), but also provide equations (based on 517 trees from 7 operations) for estimating an average based on characteristics of the current tree. The equation in subroutine FELL is:

$$AT = -1.21 + 0.157\ DBH + 0.4\ MOP$$
$$(-1.21 + 0.157\ DBH)$$
$$R^2 = .55 \qquad S_{y.x} = .64$$

Where AT = Average time to fell the tree (minutes).

DBH = Diameter of the tree at breast height (inches) from subroutine TREEV.

MOP = Method of payment for the felling crew = 0 if they are paid per thousand, = 1 if they are paid on an hourly basis.

AT and the standard error about the regression (or standard deviation if the value of AT is part of the input data) are then utilized by subroutine LOGNOR to generate the simulated felling time for the current tree. LOGNOR provides a random variable from a lognormal distribution (see appendix B) with the aid of RANDU, a random number generator maintained in the computer library at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, for use with the IBM system/370 computer (IBM Corp., 1968).

The procedure that has been outlined above is essentially the same for all operating times in the harvesting system. Differences between subroutines will generally be in the following:

- The equation(s) will be unavailable for some subroutines.
- The equation(s) themselves will, of course, be different.
- Some tasks are based on the lognormal distribution (subroutine LOGNOR) and others on the normal distribution (subroutine NORMAL).

For subroutine LIMB the equation is:

$$AT = -1.825 + 0.161\ DBH + 0.0295\ HT$$
$$R^2 = .34 \qquad S_{y.x} = 1.25$$

Where:

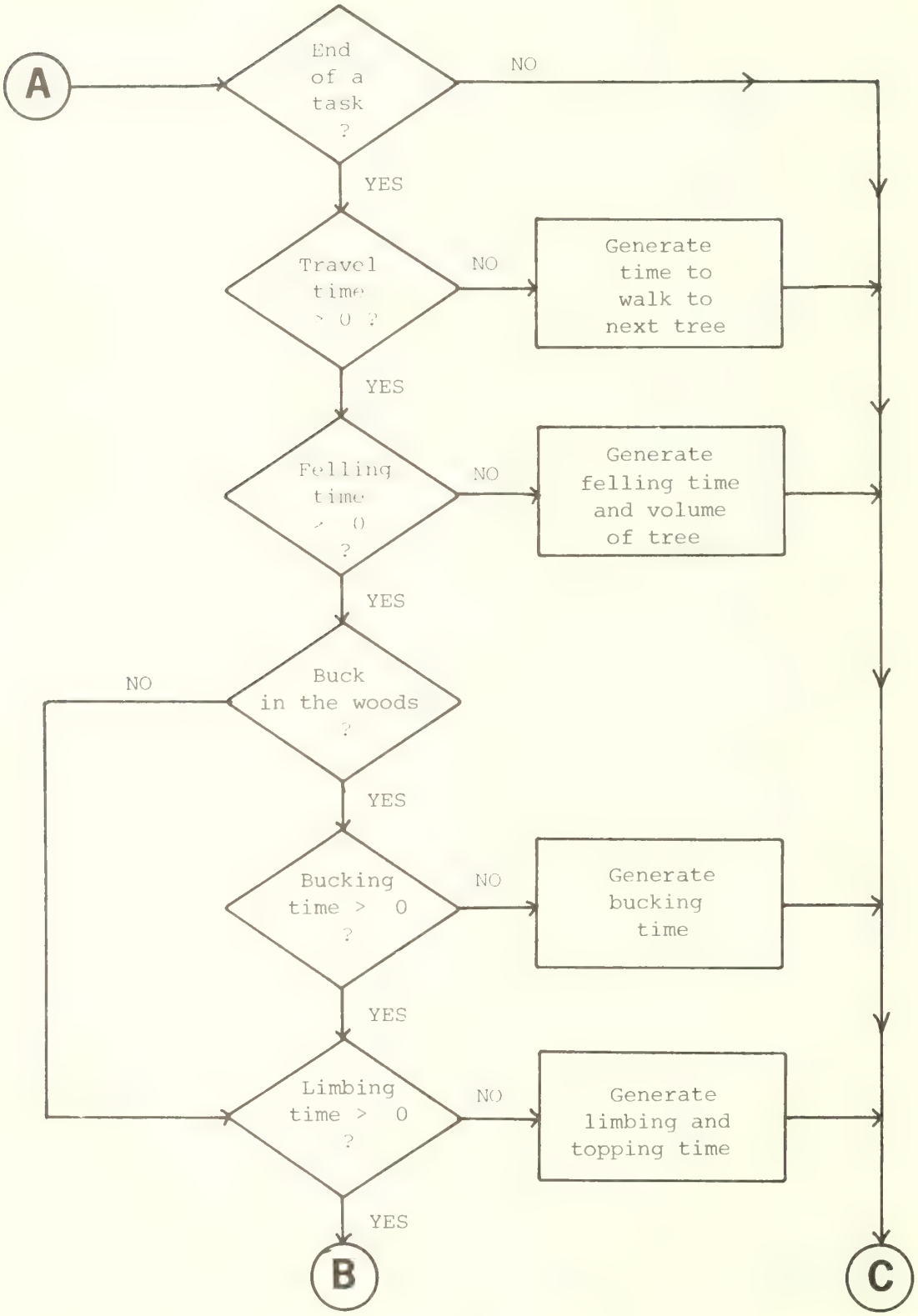
AT = Average time to limb and top the tree (minutes).

HT = Merchantable height of the tree (in feet), from subroutine TREEV.

As noted in table 1, bucking is optional; it may be done in the woods as part of the felling component, or it may be a separate operation performed at the landing (when tree-length skidding is done) (See Input Instructions, card 14.) In either case, the subroutine (BUCK) is the same. The bucking component would not be used at all if tree-length hauling is done.

Subroutine TREEV generates the DBH, merchantable height (HT), and volume (NTV) of the current tree. DBH is based on an empirical distribution for the stand of timber being harvested (see Input Instructions, Card 20). Simulated tree height is based on average merchantable height (and its standard deviation) for the timber stand; both are input variables. When DBH and height have been determined for the current tree, a volume

Figure 2.—Flow chart of felling component.



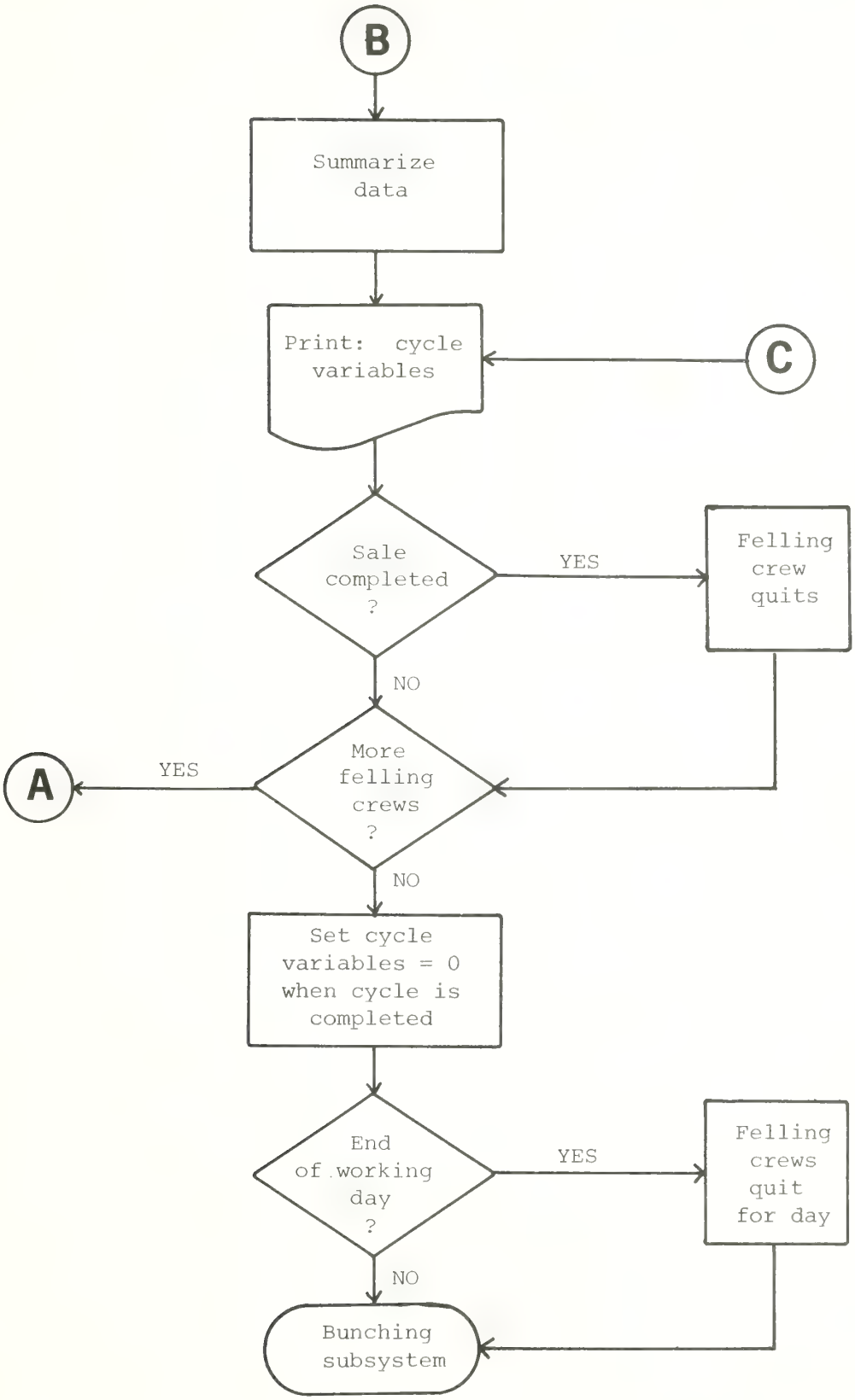

B
Summarize data
Print: cycle variables
C
Sale completed ?
YES
Felling crew quits
NO
More felling crews ?
YES
A
NO
Set cycle variables = 0 when cycle is completed
End of working day ?
YES
Felling crews quit for day
NO
Bunching subsystem

Table 1.—Expected time equations for subroutine empty

Road type	Equation	Standard error of estimate	R^2
2-lane paved	$TE_1 = 5.26 + 1.41\ DIST_1$	6.2	0.91
1-lane paved	$TE_2 = 1.00 + 2.28\ DIST_2$	2.9	.77
Gravel	$TE_3 = 3.58 + 3.41\ DIST_3$	4.7	.83
Woods road	$TE_4 = 2.22 + 8.40\ DIST_4$	5.1	.83

TE_i = Travel time in minutes.
$DIST_i$ = Hauling distance in miles.

table (also part of the input) is scanned, and the proper board foot volume is obtained.

Delay times for each task in the felling component (and all other tasks in the system) are generated by subroutine DELAY. Inputs to this subroutine are the average delay time for the task, its standard deviation, and its frequency of occurrence. DELAY calls RANDU and receives a random number between 0 and 1. If this number is less than the frequency of occurrence, a delay time will be generated, using subroutine LOGNOR; if it is greater than the frequency, the simulated delay will be set at 0. No waiting delays occur in the felling component because this is the first part of the harvesting system.

When a cycle has been completed, all operating and delay times for each task are totaled for the cycle time. All time elements and the volume are then placed in cumulative arrays for eventual conversion to daily summaries. The cycle variables are then set at zero in preparation for the next felling cycle.

The program is designed so that the felling crews may start working in the sale area a few days before the start of skidding, hauling, etc. To initiate this condition, the user merely enters the proper number of lead days on Card 16 (Input Instructions).

BUNCHING COMPONENT

The bunching component is an optional feature of T-H-A-T-S. Some logging operations employ skidders or tractors to prebunch logs (trees) before skidding them to the landing. When the system being simulated is of this configuration, the bunching component is called into use by proper coding of the input data (See Input Instructions, Cards No. 4, 28, 29, and 56).

The bunching phase has not been subdivided into tasks, hence only one operating time and one delay time are generated during each cycle (fig. 3). Subroutine BUNCH generates the simulated operating time for a bunching cycle, using a normal random process. BUNCH does not contain a predictive equation, hence an average time must be included with the input data.

In addition to generated delay, there is a possibility that waiting delay will arise if the felling crew(s) can't keep pace with the buncher(s).

The volume bunched during any one cycle is generated by subroutine SKIVOL. SKIVOL initially determines the number of trees (or logs) to be bunched in the current cycle (using subroutine NORMAL), and then generates the volume of each, using LOGVOL if the trees are bucked in the woods, or TREEV if they are bucked elsewhere.

The procedures followed by subroutine LOGVOL are similar to those used by TREEV. First a diameter and length are generated for the log. The diameter is based on an empirical frequency distribution of log diameter by length class. This distribution is part of the input deck (see Input Instructions Card 45) and should be obtained from the sale area or from past sale information of similar timber types. The simulated log length is based on a length distribution that is also part of the input. A series of equations are then used to determine log volume, using the generated di-

ameter and length. These are presently set up for the International ¼-inch log rule; however, they may be changed to suit the user. LOGVOL is currently designed for 35 diameter classes from 6 inches to 40 inches, and 5 length classes (8-, 10-, 12-, 14-, and 16-foot logs). However, this can be easily altered by changing three statements (set off by COMMENT cards) in the subroutine. The statements:

$$\text{MINL} = 8$$
$$\text{INC} = 2$$

refer to the length parameters; MINL = 8 = length of shortest log, INC = 2 = the increment (in feet) between log sizes. The statement:

$$\text{MIND} = 6$$

establishes the minimum log diameter (in this case 6 inches) to be considered in the simulation.

When a bunching cycle is completed, the variables are reset at zero; and when the day has ended, a cost, time, and production summary is printed.

When there are two or more felling crews and/or two or more bunchers, the interaction between the two components is a bit sticky. Consequently, a decision rule was programmed into the simulator that may be somewhat arbitrary, but nevertheless is fairly realistic. If the number of bunchers is equal to the number of felling crews, they will be matched up, feller No. 1 with buncher No. 1, feller No. 2 with buncher No. 2, etc. If the numbers are unequal, then the buncher(s) will alternate with the felling crew(s) in a systematic manner throughout the day.

SKIDDING COMPONENT

The skidding component is divided into five tasks: outbound or outturn time (landing to woods), hookup time, skidding or inturn time (woods to landing), unhooking time, and positioning time (decking logs or trees at the landing). Completion of the cycle means that one turn of logs (trees) has been brought from the felling area to the landing (fig. 4).

Subroutine RETURN permits the generation of travel time by using either an average time or an equation. The equation, based on 195 observations from seven operators, is as follows:

$$\text{AT} = 0.558 + 0.0022\ \text{ASD} - 1.1535\ \text{SLOPE}$$
$$R^2 = .77 \qquad S_{y.x} = 1.09$$

Where:

AT = The average outturn time in minutes.
ASD = The skidding distance in feet.
SLOPE = An indicator of the aspect of the skidroad grade. If the trip to the woods is on level ground or downhill, SLOPE = 1, if uphill, SLOPE = 0.

The skidding distance (ASD) varies with the amount of timber removed. To permit this, the simulator must first estimate the maximum volume that will be skidded to an individual landing. The area serviced by a landing is assumed to be one-eighth of the area defined by a circle with radius equal to the maximum expected skidding distance. Of course, this assumption can be easily altered to one-fourth or one-half, etc., by changing the denominator in statement 13 + 6 (this value equals 8.0 in the present version). This area-per-landing (in acres) is simply multiplied by the average volume per acre (VPA) to arrive at the maximum volume skidded to a given landing (MAXVOL).

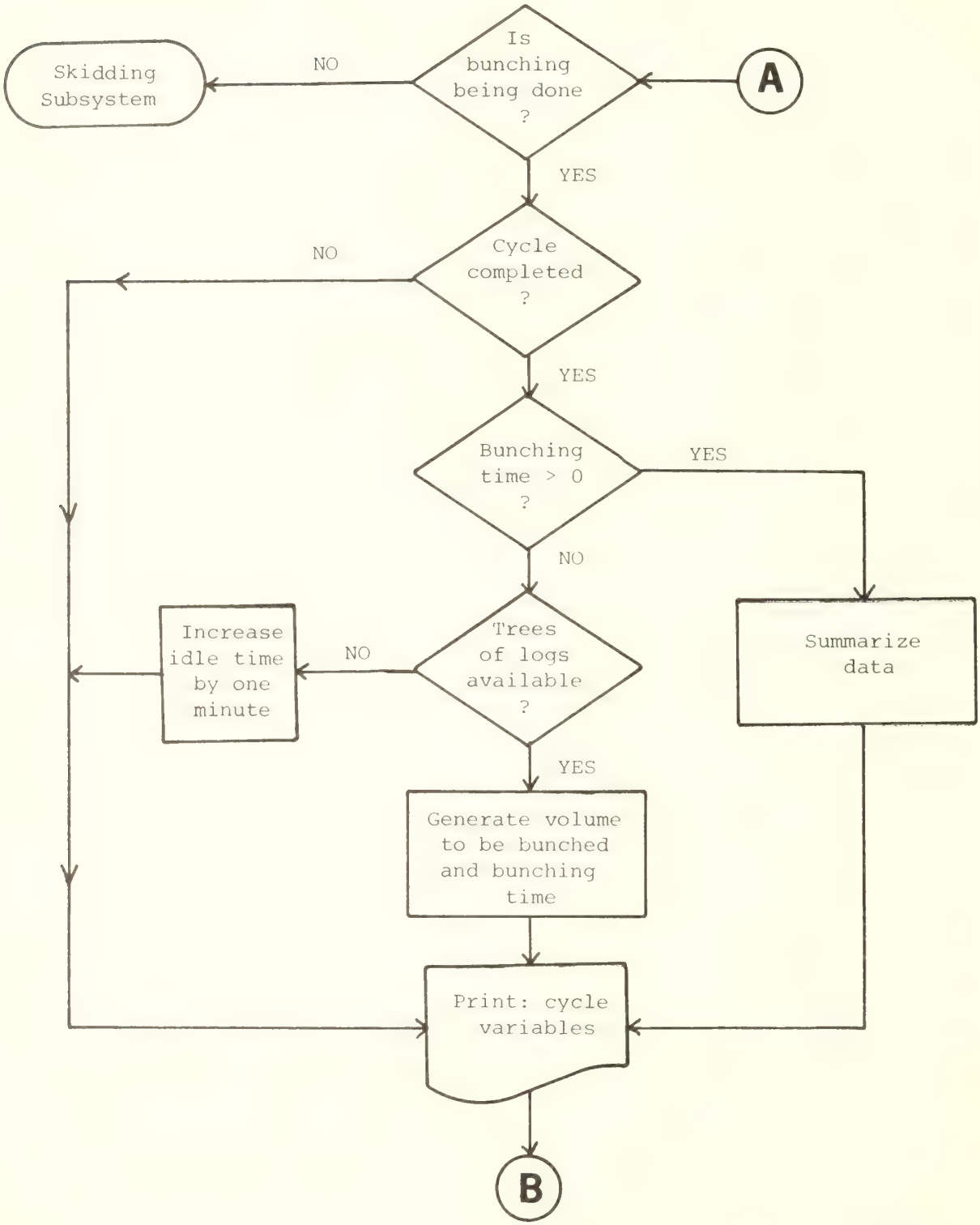
When the accumulated volume (IVMAX) that has been skidded to a landing equals or exceeds MAXVOL, it becomes time to move to another landing. This is explained further in the loading component section; however, it was necessary to introduce IVMAX at this point in the discussion. IVMAX is used in the following equation to determine the skidding distance for each trip:

$$\text{ASD} = \sqrt{\frac{(43{,}560)\ (8)\ (\text{IVMAX})}{(\pi)\ (\text{VPA})}}$$

This is simply the equation used for calculating MAXVOL, rewritten in terms of ASD.

Subroutine SKIVOL is used to generate the volume of a turn, and this has been discussed in the section describing the bunching component. Subroutine HOOKUP is used to gener-

Figure 3.—Flow chart of bunching component.



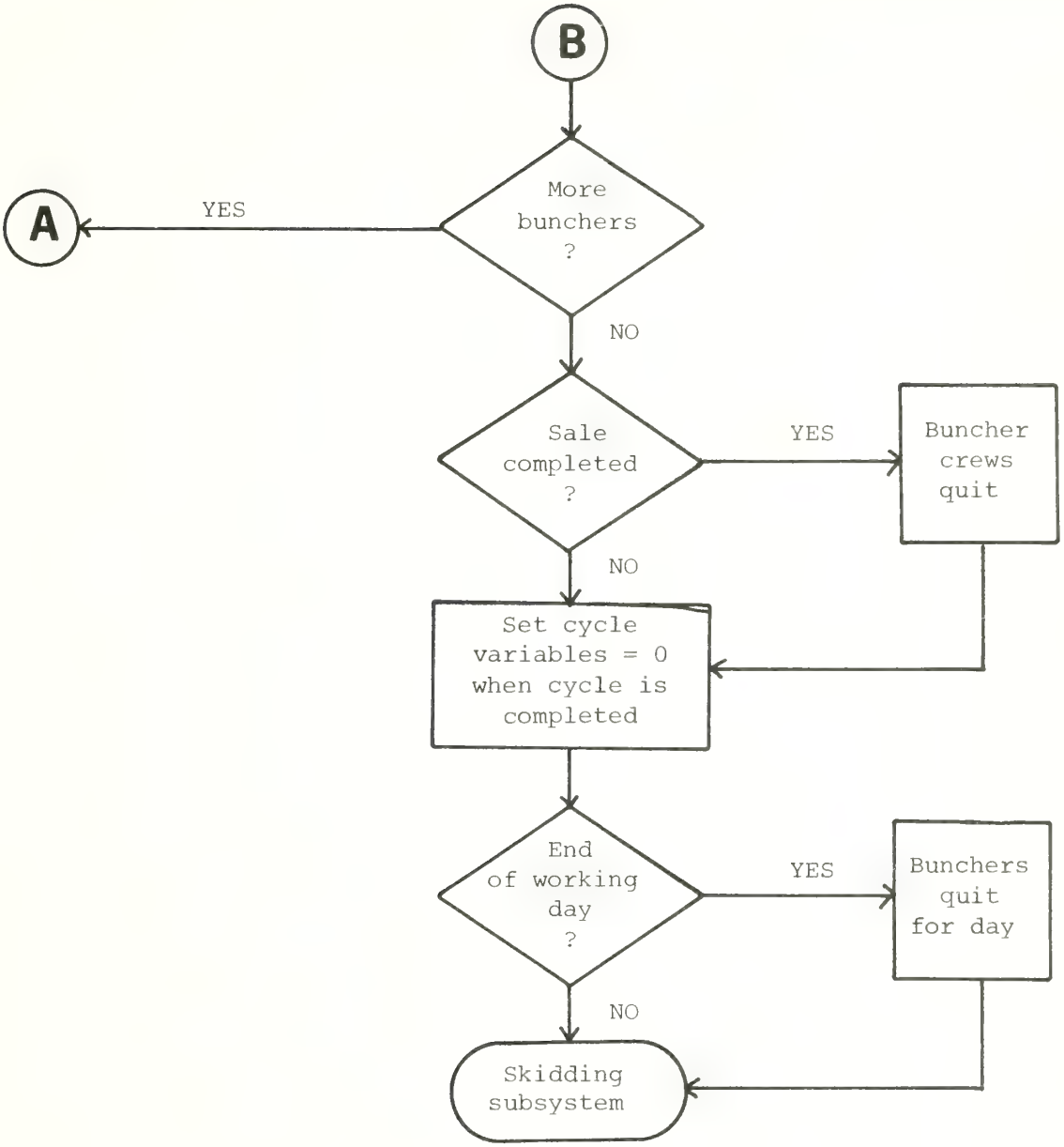
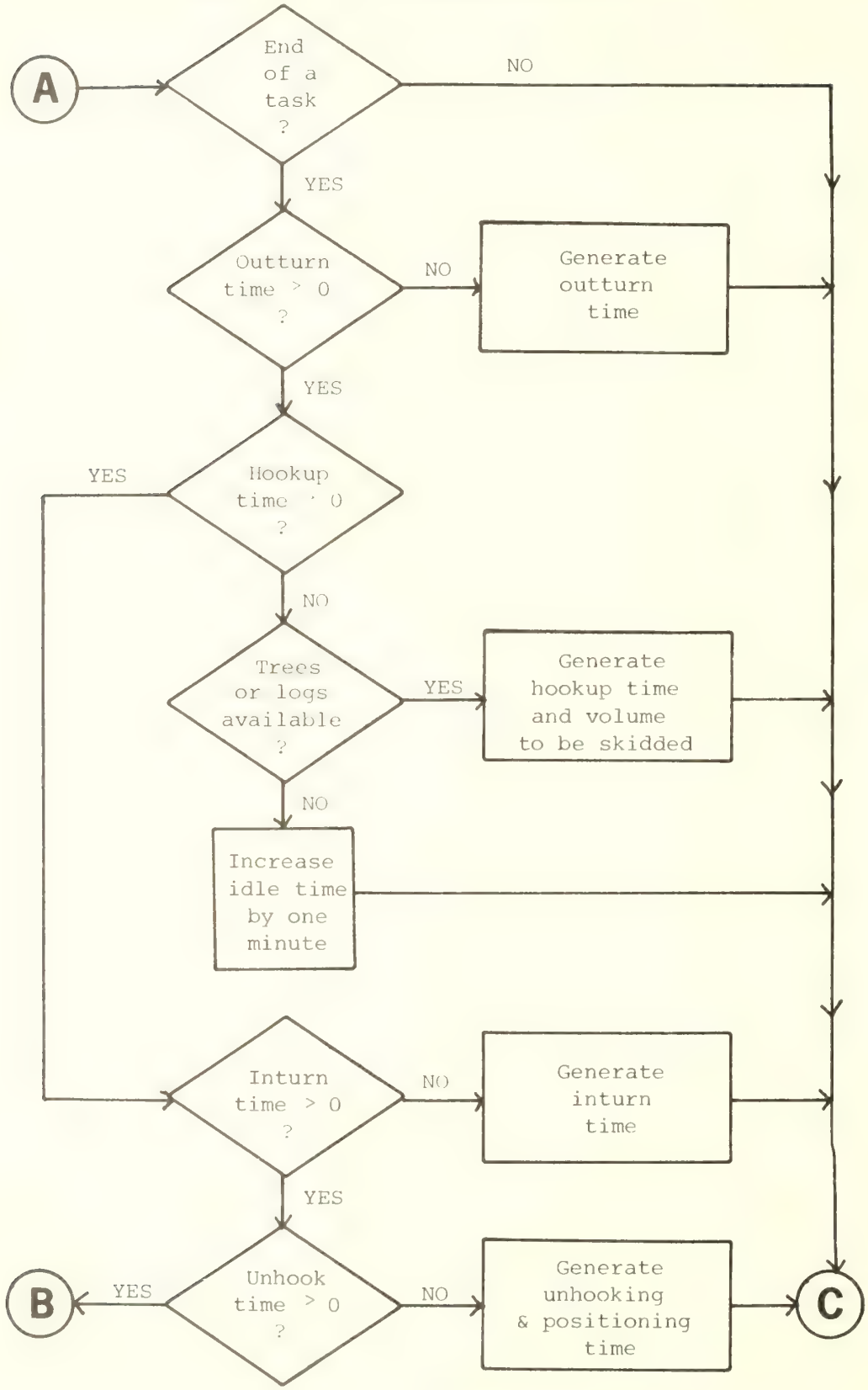
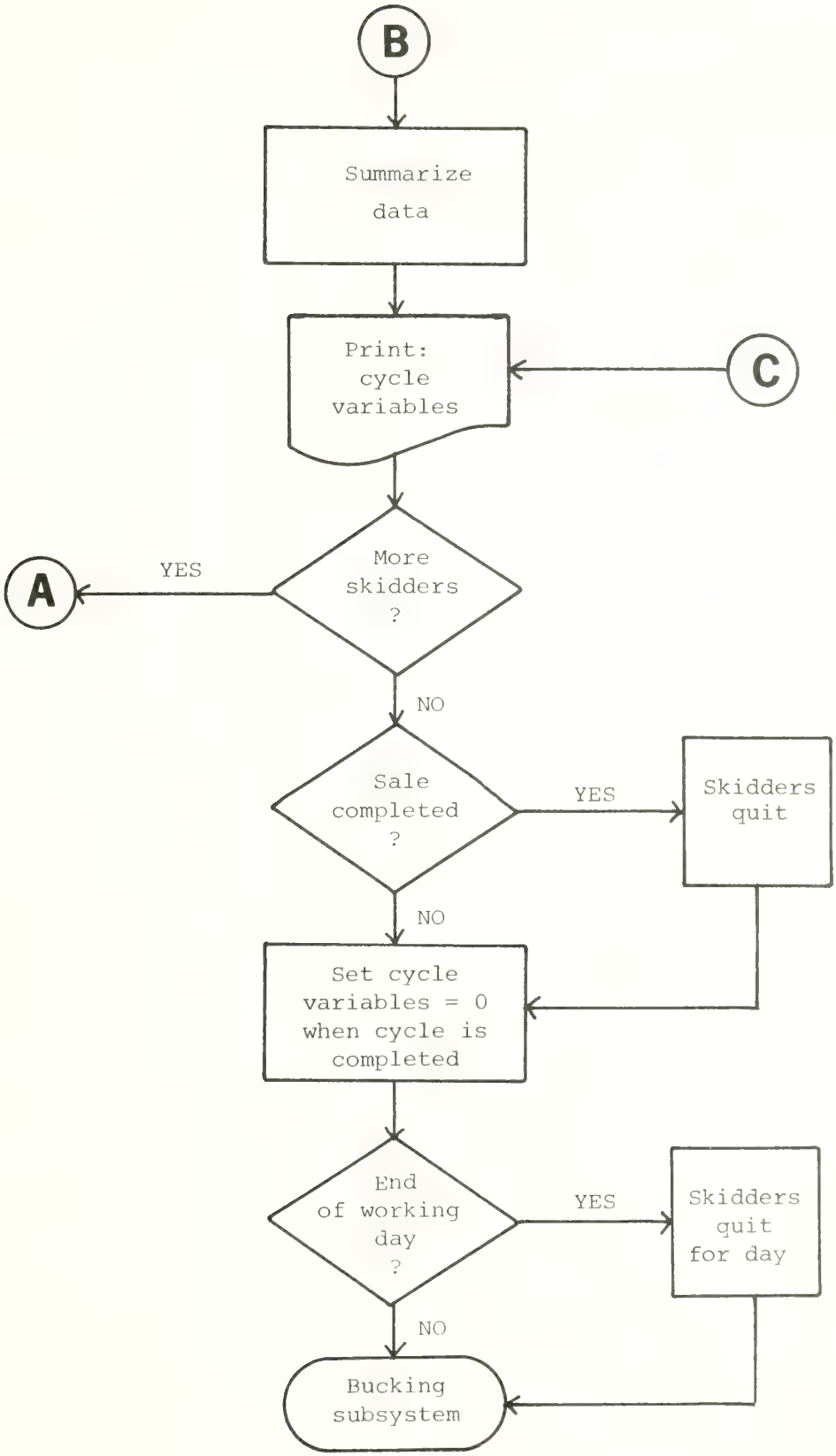

B
More bunchers ?
YES
A
NO
Sale completed ?
YES
Buncher crews quit
NO
Set cycle variables = 0 when cycle is completed
End of working day ?
YES
Bunchers quit for day
NO
Skidding subsystem

Figure 4.—Flow chart of skidding component.




B
Summarize data
Print: cycle variables
C
More skidders ?
YES
A
NO
Sale completed ?
YES
Skidders quit
NO
Set cycle variables = 0 when cycle is completed
End of working day ?
YES
Skidders quit for day
NO
Bucking subsystem

ate the time required for hooking up the turn of logs (trees). There is no equation available; however, the subroutine permits the use of an average fixed time in conjunction with an average variable time (per tree or log) if the user wishes. These options are explained in the instructions for preparing the input data.

Generation of the simulated skidding time (from woods to landing) relies on the use of subroutine INTURN. This subroutine allows the user to employ an average (expected) time (read as input) or to compute this figure by means of the following equation:

$$AT = 4.37665 + 0.00142\ IV + .00082\ ASD + 2.59108\ SLOP1 + 2.13999\ SLOP2 - 3.15239\ MACH$$

$$R^2 = .51 \qquad S_{y.x} = 1.81$$

Where:

AT = The average inturn time in minutes.

IV = Volume skidded during the current turn (board feet) from subroutine SKIVOL.

ASD = Distance that the turn is skidded (feet).

SLOP1 = 1 if the turn is skidded uphill to the landing, = 0 if on level ground or downhill.

SLOP2 = 1 if the turn is skidded over level terrain to the landing, = 0 if uphill or downhill.

MACH = 1 if the skidder is rubber-tired with articulated frame, = 0 otherwise.

Unhooking the turn at the landing involves subroutine UNHOOK, and this is simply a procedure for using an average value (with its standard deviation) from the input data.

Occasionally the skidder will have to position some of the logs (trees) at the landing. If this occurs within a particular cycle, subroutine POSITN is used to generate the time involved. The inputs to this routine are an average time, its standard deviation, and an expected frequency of occurrence (used as in subroutine DELAY).

The generated delay times are obtained by subroutine DELAY, as discussed in the felling component section. Waiting delays that may arise can be attributed to two sources. The skidder may have to wait for logs (trees) in the woods and this may be caused by a felling crew, a buncher, or both.

When a cycle has been completed, the trees go into a bucking queue if bucking is done at the landing; if trees are bucked elsewhere the skidded logs (trees) are placed in a loading queue (the deck).

As with bunching, there is a considerable amount of interaction between the skidder(s) and the preceding function (either bunching or felling). This is handled in the same manner and with the same decision rules as used in the bunching component.

BUCKING COMPONENT

The simulator determines first whether bucking is performed in the woods, at the landing, or at the mill yard. If in the woods, program control transfers to the loading component; if at the landing, the bucking component is utilized; if at the mill yard, bucking is not considered.

The bucking component is composed of the bucking and marking time elements (generated as one value) and the delay times. Completion of a bucking cycle means that one (or sometimes two) trees have been bucked and the volume added to that available for loading (fig. 5).

Three subroutines are required in the bucking component. Subroutine TREEV generates the volume, diameter, and length of the tree to be bucked (as discussed previously). The simulated time for marking and bucking the tree is provided by subroutine BUCK. The average, or expected, time is obtained from the input deck or from the following equation (based on 317 observations from 7 operations):

$$AT = -5.244 + 0.244\ DBH + 0.107\ HT$$

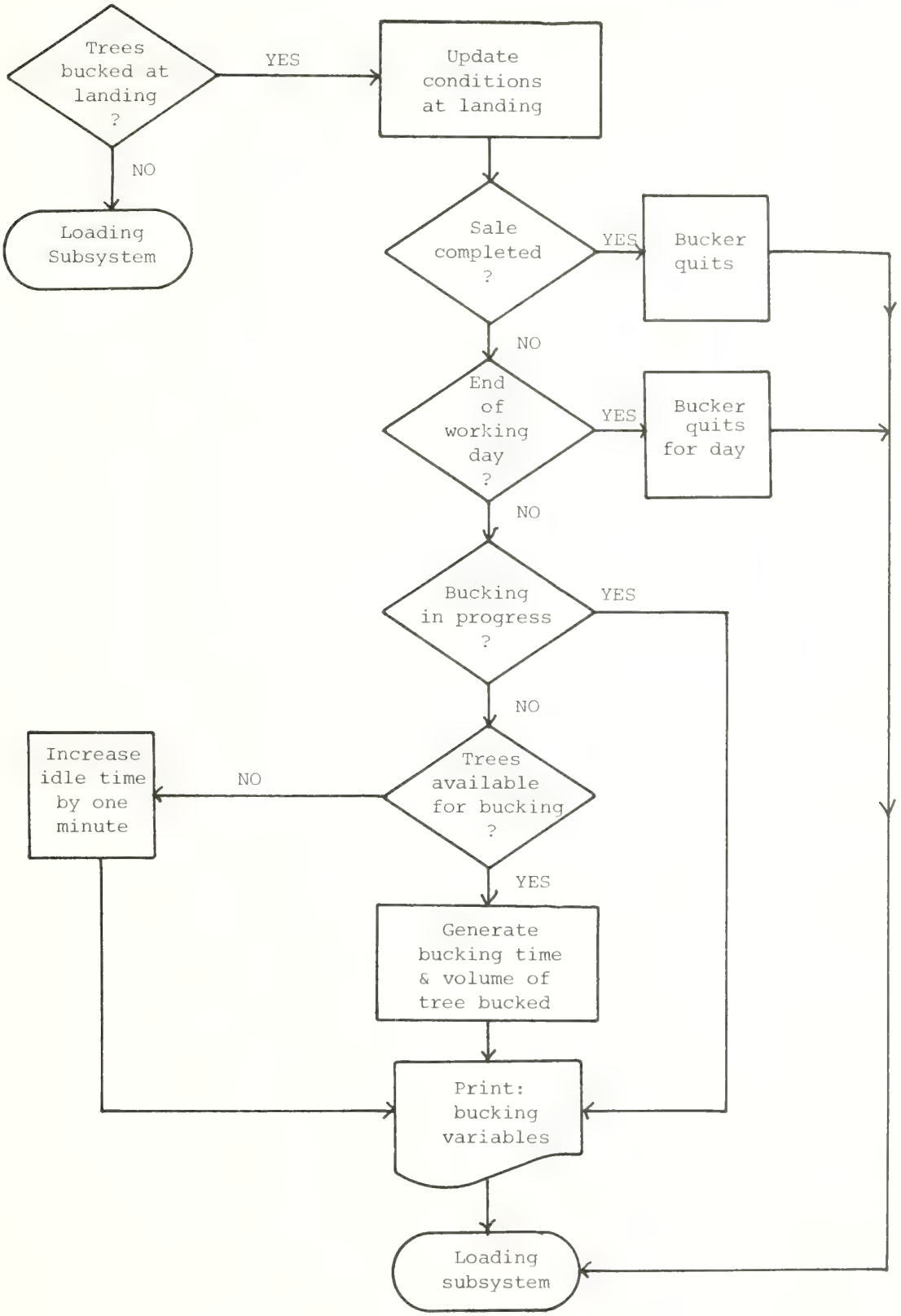
$$R^2 = .56 \qquad S_{y.x} = 1.01$$

Where:

AT = The average marking and bucking time in minutes.

DBH = Diameter (breast height) of the tree being bucked, from subroutine TREEV.

Figure 5.—Flow chart of bucking component.



HT = The height (length) of the tree being bucked, from subroutine TREEV.

When the tree has been bucked, this volume becomes available for loading, and it is added to the loading queue.

Delay time may be generated during the bucking of a tree and/or it may arise if the bucking crew has to wait for trees to arrive at the landing. This wait may now be attributable to any one (or all) of three preceding operations (felling, bunching, and skidding).

LOADING COMPONENT

Before any logs can be loaded, the simulator must first determine whether both logs and a truck are available. If either condition is not met, then waiting delay time will accrue. The loading section also contains the procedures for selecting the truck that will be loaded next. When trucks arrive at the landing, they are placed in a waiting line if another truck is currently being loaded. When loading is completed, the truck that has been waiting the longest time is selected to be loaded next.

The procedures involved in loading are detailed in figure 6. A loading cycle ends when a log has been positioned on the truck, and the elements of this cycle are simply the operating time and any delay that may arise. Subroutine LOADER generates these two time elements as well as calling for subroutine LOGVOL (or TREEV if tree-length hauling is done) to generate the log's volume. LOGVOL and TREEV have been explained in discussing the bunching and felling components, and their use in loading is the same. The operating time is obtained quite simply from subroutine LOGNOR and is based on an expected value from the input data (card 49).

Delay time is either generated (caused by the loader itself) or caused by waiting for logs or trucks. There are four possible sources of delay (felling, bunching, skidding, and bucking) that would cause the loader to set idle if logs weren't available. And if there were no trucks at the landing, the loader would be idle until one arrived.

After each log is placed on the truck, the program checks to see whether the truck is loaded. This is done by comparing volume on the truck to the expected load volume of the vehicle. Expected load volumes are read in as part of the input data (card 51).

After the truck is loaded, the times and volume are added to cumulative arrays; and at the end of the day a cost, time, and production summary is printed.

Provision is also made for moving the landing as cutting progresses through the stand. The decision rule for determining when to make the move has been discussed in the skidding section. When the time to move has been reached, the skidder(s) start to skid to the new landing area. If bucking is done at the landing, the bucking crew (if different from the loading crew) moves to the new location when they have completed their task at the old landing. When all logs at the old landing have been loaded, the loader is prepared for moving to the new site. To generate the time required for the move, subroutine BUNCH is again utilized. Since this is a simple routine having no specific equations, it is used instead of adding another subroutine designed for moving only. The generated time is based on an expected value (and its standard deviation) from input card 33.

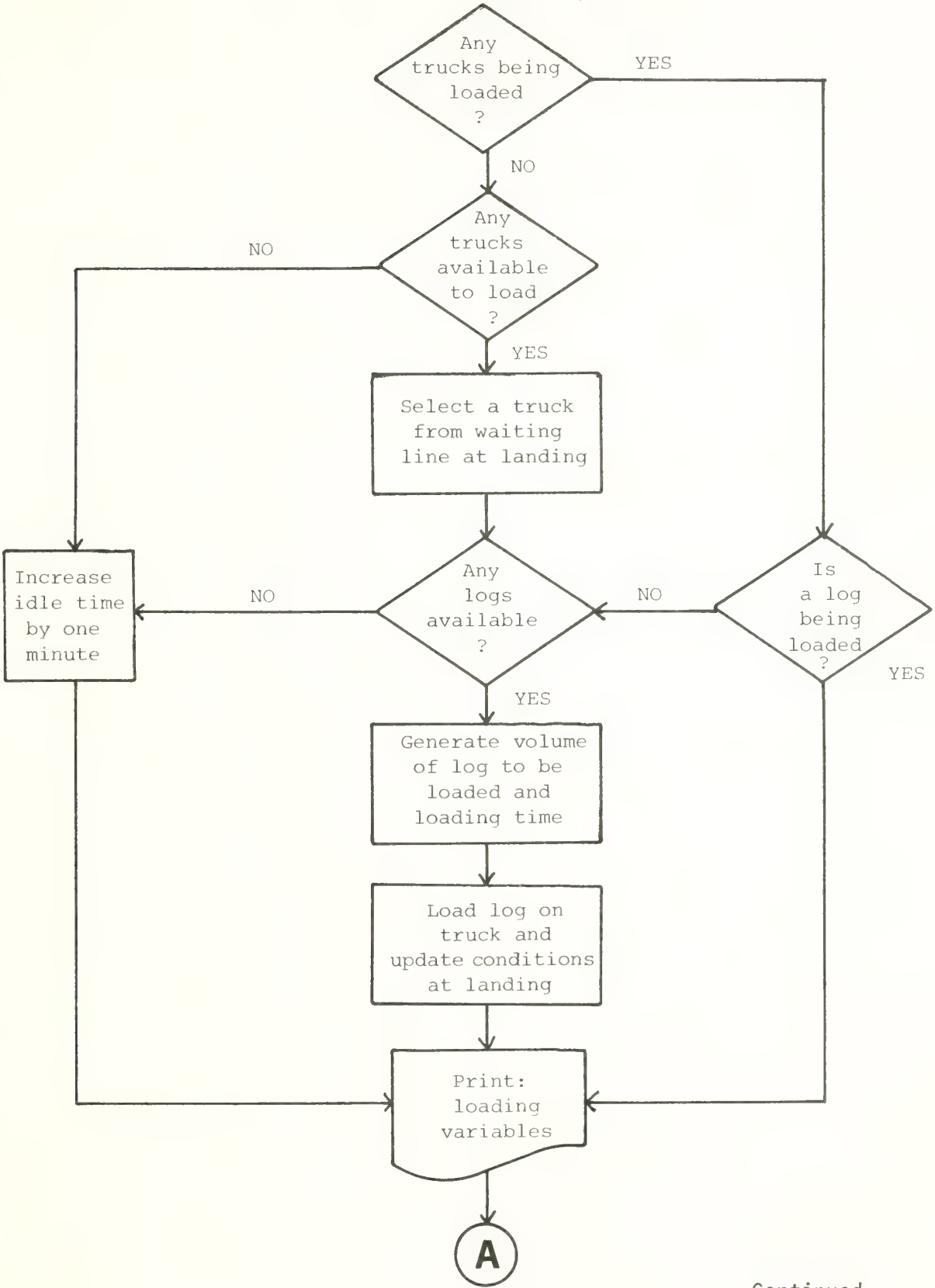
HAULING COMPONENT

Hauling consists of four tasks: the empty travel from a mill to the woods, the loading time, the loaded travel from woods to mill, and the unloading time at the mill yard. When a hauling cycle is finished, a truckload of logs has been delivered to the mill (fig. 7).

Most of the subroutines used in the hauling segment of T-H-A-T-S have been discussed before, hence only those introduced here will be explained.

Subroutine EMPTY generates the travel time from the mill to a woods landing. It incorporates four equations: one for each of four road types (table 1). The mechanics of this subroutine are best illustrated by considering an example. Suppose the one-way hauling distance is 29.7 miles, 24.7 miles of 2-lane paved roads, 1.4 miles of 1-lane paved roads, 1.3 miles of gravel roads, and 2.3 miles of woods

Figure 6.—Flow chart of loading component.



Continued

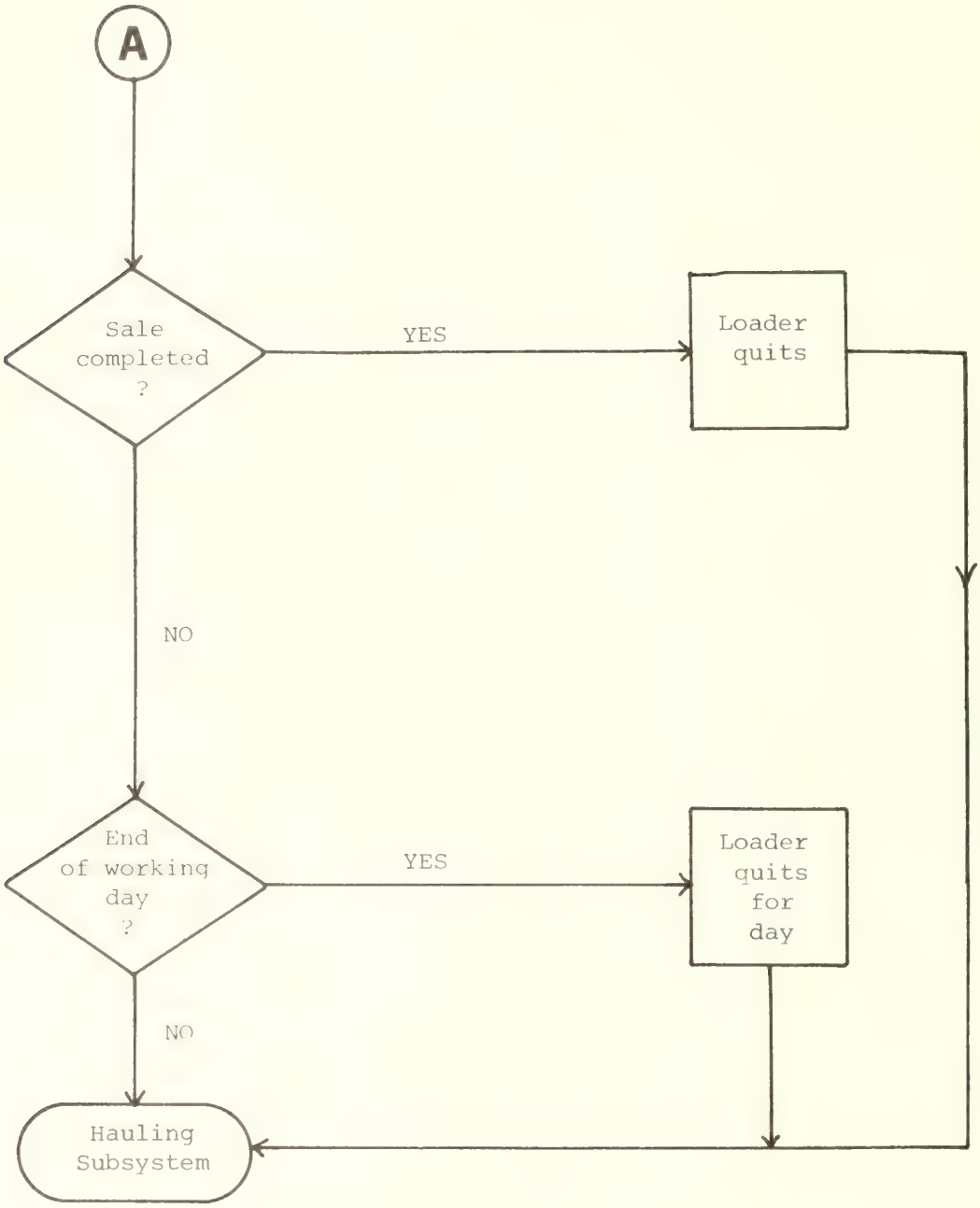
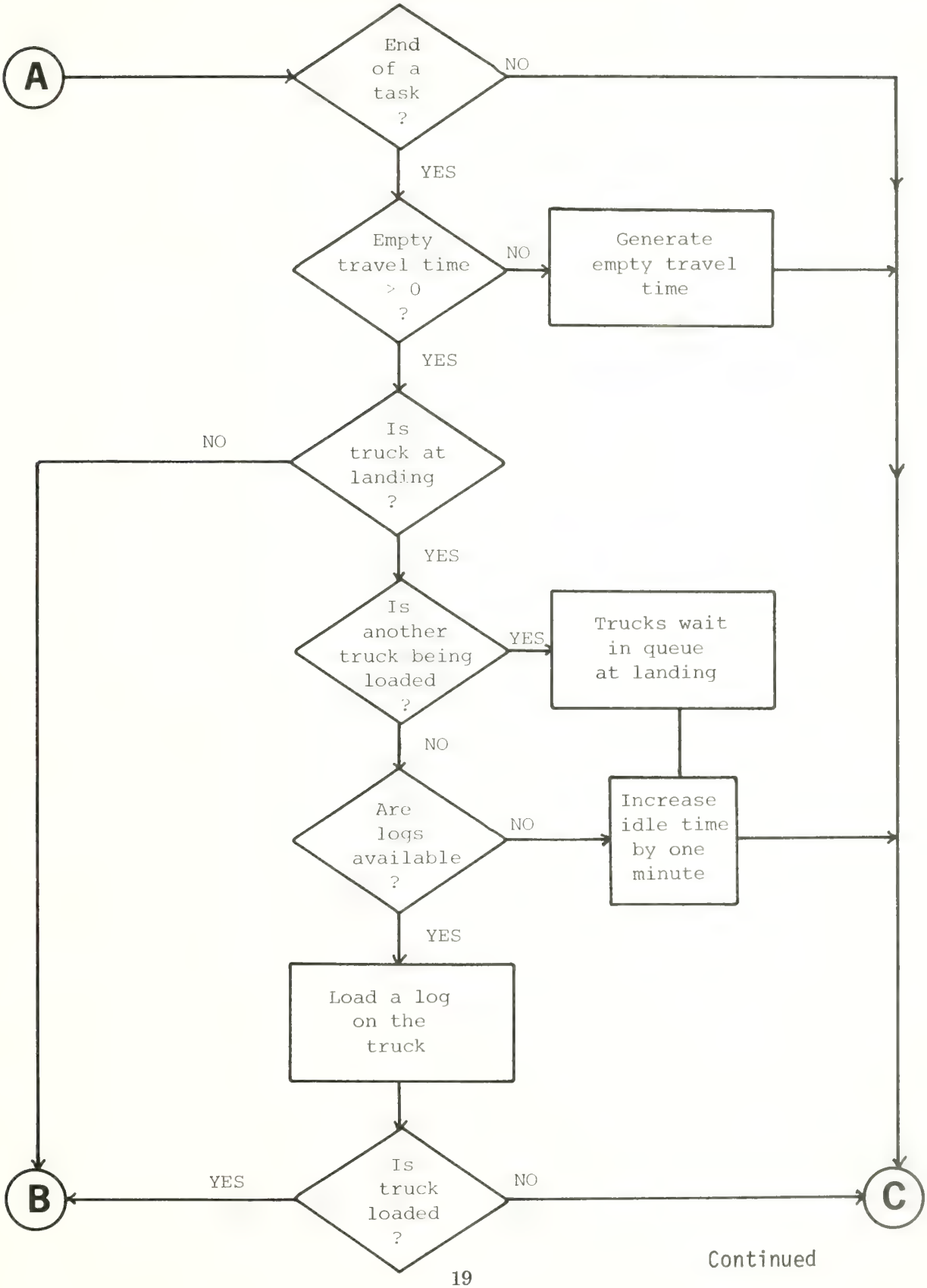
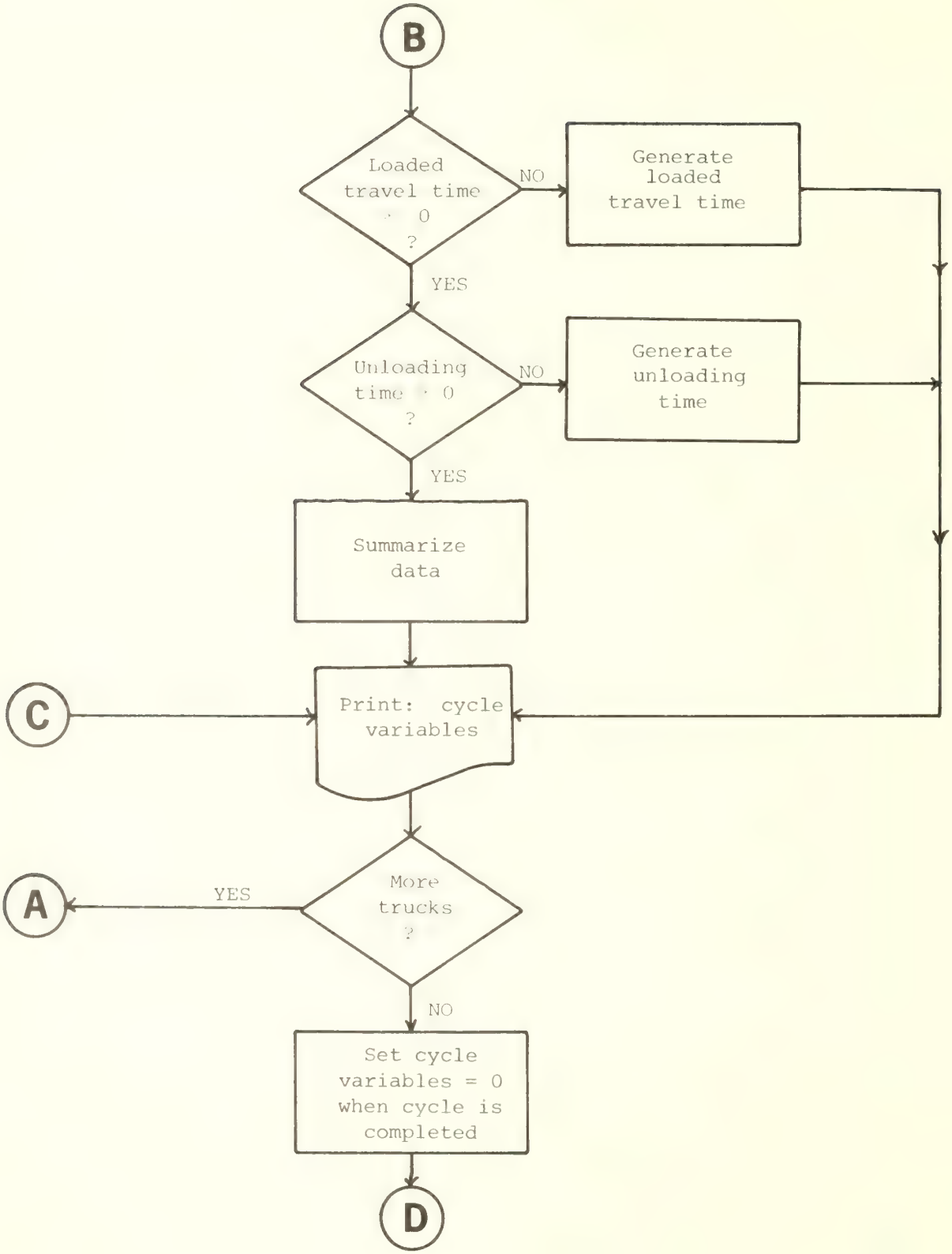
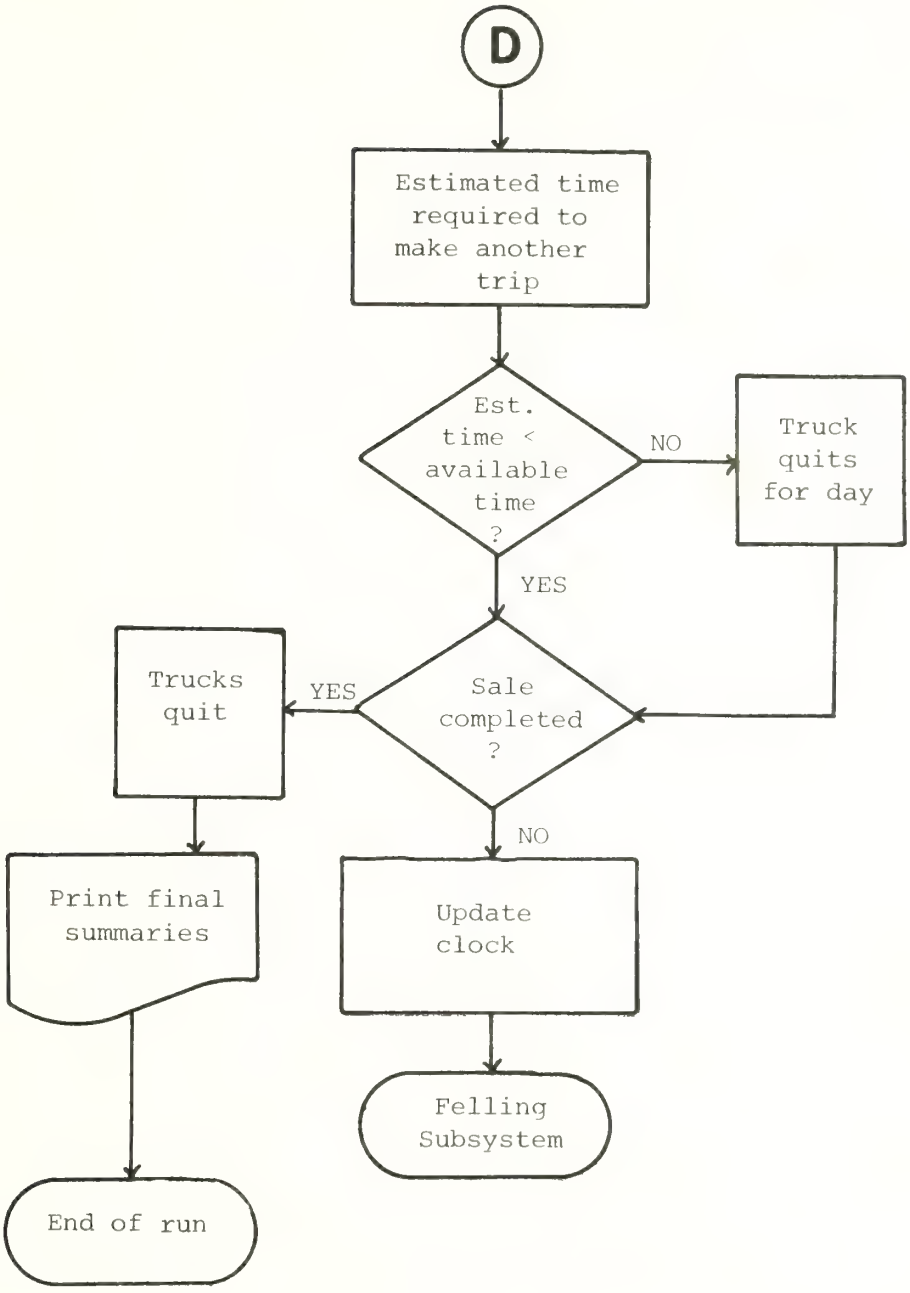

A
Sale completed ?
YES
Loader quits
NO
End of working day ?
YES
Loader quits for day
NO
Hauling Subsystem

Figure 7.—Flow chart of hauling component.



Continued


B
Loaded travel time > 0 ?
NO
Generate loaded travel time
YES
Unloading time > 0 ?
NO
Generate unloading time
YES
Summarize data
C
Print: cycle variables
More trucks ?
YES
A
NO
Set cycle variables = 0 when cycle is completed
D



roads. Substituting these values in the appropriate equations in table 1, we find the expected travel times for each segment are 40.1, 4.2, 8.0, and 21.5 minutes, respectively. These expected times, along with the appropriate standard error of estimate values (table 1), are then used in subroutine NORMAL to generate simulated times for each road segment during a given hauling cycle. The sum of these segment times becomes the simulated time to make the trip from mill to the woods.

Subroutine HAUL, which generates the travel time from woods to mill, functions in the same manner as that described for EMPTY. The equations used in HAUL are presented in table 2.

When a loaded truck reaches the mill yard, subroutine UNLOAD is called so that a simu-

Table 2.—Expected time equations for subroutine HAUL

Road type	Equation	Standard error of estimate	R^2
2-lane paved	$TH_1 = 5.91 + 1.76\ DIST_1$	8.1	0.90
1-lane paved	$TH_2 = 2.01 + 2.73\ DIST_2$	4.3	.69
Gravel	$TH_3 = 4.00 + 4.34\ DIST_3$	6.0	.82
Woods road	$TH_4 = 3.78 + 11.23\ DIST_4$	7.4	.80

TH_i = Travel time in minutes.
$DIST_i$ = Hauling distance in miles.

lated unloading time can be obtained. UNLOAD utilizes an expected time in conjunction with its standard deviation to generate this time element.

When a truck arrives at a landing in the woods, it is placed in a waiting line if the loader is occupied with another truck. Waiting delay time then accrues until the status of the truck is changed. If the landing is vacant when the truck arrives, the loading phase begins immediately if logs are available; if not, waiting delay time accrues until logs become available for loading.

After the truck is loaded, the driver usually spends a few minutes adjusting the load chains. This time is generated by subroutine DELAY. Provision is also made for generating other self-caused delays during other phases of the hauling cycle.

It is also possible to have the trucks (for those operations with more than one) start at different times in the morning, a staggered departure from the mill (or home). This is accomplished by using lag times that are read in for each truck (input data, card 15).

Both end-of-day and end-of-sale routines for hauling are similar to those used in the other components. However, with hauling, it is possible to have the truck end the day at the landing. In other words, the truck may remain in the woods overnight, either empty or partially loaded. This would occur if the log supply should run out before a truck is loaded, and the felling, skidding, or bucking crews have quit for the day.

ROADBUILDING COMPONENT

This is a relatively simple part of the simulation model because the costs of roadbuilding are treated as an add-on item, computed at the end of the sale. Total roadbuilding cost is computed by subroutine ROADS as follows:

$$RBC = (RB_1)\ (BC_1) + (RB_2)\ (BC_2) + (RB_3)\ (BC_3) + (RB_4)\ (BC_4)$$

Where:

RBC = Total roadbuilding cost.
RB_1 = Miles of main skidroads built.
RB_2 = Miles of spur skidroads built.
RB_3 = Miles of main haul roads built.
RB_4 = Miles of secondary haulroads built.
BC_1 = Construction costs per mile for main skidroads.
BC_2 = Construction costs per mile for spur skidroads.
BC_3 = Construction costs per mile for main haulroads.
BC_4 = Construction costs per mile for secondary haulroads.

The values for RB_1 and RB_2 may be read in with other input data (card 44), or certain assumptions contained in the subroutine may be used instead. If RB_1 and RB_2 are left blank, the simulator automatically assumes that 65 feet of main skidroad and 75 feet of spur road will be constructed for each acre that is logged (*Smithson and Phillips 1970*). Also, if BC_2 is not entered as input, the program will assign a cost-per-mile figure equal to one-fourth of BC_1.

If the separate values of RB_3 and RB_4 are unknown, the simulator uses $DIST_4$ (miles of

woods road) as the basis for computing building costs of haulroads. If unknown, RB_3 and RB_4 should be left blank on Card 44. Using $DIST_4$ results in the same cost factor (BC_3) being used for all haulroad construction.

Roadbuilding costs are computed only when the sale has been completed, hence they are only shown in the final table of costs and times. Roadbuilding cost per MBF is based on the total volume hauled from the sale area.

COST COMPONENT

The computation of system cost requires that first the machine rate of each piece of logging equipment in the operation be calculated. T-H-A-T-S does this by means of two subroutines (COSTS and COST), and cost data supplied as part of the input (card 56).

A separate input card is needed for each machine or crew in the logging system. For example, if two fellers are working on the same sale, then two cost-data cards are needed for the felling component. If only one skidder is utilized, then only one card is needed for the skidding component; however, if more than one man is working with the skidder, then the hourly wage rate on this card should reflect the cost of the other men. These rules apply to all other system components as well.

The subroutines calculate two machine rates ($/hour) for each machine or crew in the system; one is applied to the time spent in production (operating time) during the day and the other to time spent idle (delay time). Operating-time machine rates include all cost items, whereas delay-time rates only include the fixed costs (*Martin 1971*).

The operating-time machine rate varies from day to day because the amount of consumables (gas, oil, etc.) changes if the distance traveled changes. A truck may make three trips today and perhaps only one tomorrow. Repair costs and tire wear also vary with the amount of use the vehicle is subjected to.

At the end of each day's operation, and at the end of the sale, the appropriate machine rates are applied to the operating and delay times for all equipment in the system. Summing over all phases of the system provides the daily cost (or sale cost), and dividing by production gives the harvesting cost per MBF (See next section on output from T-H-A-T-S).

OUTPUT FROM T-H-A-T-S

Four types of printed output are generated by T-H-A-T-S:

- System status information.
- Time summaries.
- Production summaries.
- Cost summaries.

The status of the system can be printed for each minute throughout the day, only once a day, or at any interval between these extremes (figs. 8, 9, 10, and 11). The input used to generate the output in these examples is presented in the input instructions.

The interpretation of the columns headed TO, TL, TI, and TU are presented in figure 12. The values found in these columns are simulated minutes for the current cycle. The remaining column headings are explained below:

TP — Time required to position logs at the landing, when it occurs, for the current cycle.

GDT — The generated (self-caused) delay time for the current cycle.

WDT — The waiting delay time that arises during the current cycle.

TOTAL — The total cycle time; TO + TL + TI + TU + TP + GDT + WDT; when the cycle is complete, = 0 otherwise.

VOL/C — The volume (board feet) produced during the current cycle.

	Bucker	*Loader*
VOLLEFT	Volume at the landing that remains to be bucked.	Volume at the landing that is available for loading.
VOLDONE	The cumulative volume bucked during each day; set to zero every morning.	The cumulative volume loaded during each day; set to zero every morning.

CUMOT The cumulative operating time for each day; set to zero every morning.

CUMDT The cumulative delay time for each day; set to zero every morning.

By examining the output in figure 8, it is easy to see the methodology of T-H-A-T-S in action. For example, at 8:00, a time of 1 minute was generated for walking to the first tree by the feller. At 8:01 (1 minute later) the felling time of 3 minutes was generated along with the tree's volume (51 board feet). When the 3 minutes have elapsed (at 8:04), the limbing and topping time of 1 minute is generated. And at 8:05, the first felling cycle has been completed and the total time of 5 minutes is printed. Note that no delay time occurred during this cycle; however, the buncher had to wait for this first tree and at 8:05 the accumulated waiting delay time for the buncher is 5 minutes.

Time, production, and cost summaries are printed at the end of each day (and at the end of the simulation run). An example of this can be seen in figure 11.

The production and cost summary is self-explanatory. However, the time summary requires some discussion. The interpretation of these data is best explained by an example or two. Let's consider the information contained in figure 11—the summary of the first day's activities for our illustrative problem (system 272):

The first two rows in the time summary contain felling information; and in the column labeled "Fell", we see the values 147 and 271. This means that 147 minutes were spent during the first day in actually felling trees (operating time). Under the heading "Trees", we find 94—meaning that 94 trees were felled during the day. Therefore, the average felling time was 1.6 minutes (147/94). The standard deviation about the average can also be computed, because 271 is the sum of squares for the individual felling times:

$$s = \sqrt{\frac{271 - (147^2/94)}{94 - 1}} = 0.67 \text{ minutes}$$

Delay-time statistics can also be computed easily by using the figures under the headings DF and F(DF). F(DF) = 8 indicates that delay time occurred during the felling phase of 8 of the 94 trees that were cut during the first day. Therefore, the frequency of occurrence = 0.085 (8/94) or 8.5 percent. The average delay time during the felling phase (when it occurred) was 3.1 minutes (25/8) with a standard deviation of:

$$s = \sqrt{\frac{155 - (25^2/8)}{8 - 1}} = 3.31 \text{ minutes}$$

The same calculations can be performed on the remaining data in the time summary. These values are cumulative so that at the termination of a run, the last time summary printed contains values for the entire run.

The cost summary (including production figures) is also depicted in figure 11. This is printed daily and at the end of the simulation run. It should be noted that the bottom figure in the cost/MBF column is not the sum of this column, but rather is the overall system cost per MBF, calculated as follows:

$$\text{Total system cost/MBF} = \left(\begin{matrix}\text{Total} \\ \text{system} \\ \text{cost}\end{matrix} \Big/ \begin{matrix}\text{Volume} \\ \text{delivered} \\ \text{to mill}\end{matrix}\right) 1000$$

and using the data shown in figure 11:

$$\text{Total system cost/MBF} = (\$413.48/5143)\ 1000 = \$80.40$$

MODEL VALIDITY

The question arises: "How good is T-H-A-T-S?; how much faith should we have in the simulation results?" This is a rather difficult question to answer because, as with most research, the findings and recommendations are based on sample data and generalizations drawn from these data. However, we have made a large number of runs with T-H-A-T-S, using data from seven logging operations and the results show that for most attributes, the simulator resembles the real-world quite well.

As would be expected when an average time and its standard deviation for a particular function are used (read as input), the simulator generates values having an average (and

Figure 8.—A portion of the output from the first day of simulated operation for the example problem, showing the system status printed every minute.

DAY NO. 1 EXAMPLE PROBLEM -- SYSTEM 272

TIME		TO	TL	TI	TU	TP	GDT	WDT	TOTAL	VOL/C	VOLLEFT	VOLDONE	CUMOT	CUMDT		
8:00	FELL--1	1	0	0	0		0		0	0					FELLER	1
8:00	BUNCH-1	0					0	0	0	0					BUNCHER	1
8:00	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:00	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:00	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:00	LOADER		0					0		0	0	0	0	0	LOADER	
8:00	BUCKER		0					0		0	0	0	0	0	BUCKER	
8:01	FELL--1	1	3	0	0		0		0	51					FELLER	1
8:01	BUNCH-1	0					0	1	0	0					BUNCHER	1
8:01	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:01	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:01	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:01	LOADER		0					1		0	0	0	0	0	LOADER	
8:01	BUCKER		0					1		0	0	0	0	0	BUCKER	
8:02	FELL--1	1	3	0	0		0		0	51					FELLER	1
8:02	BUNCH-1	0					0	2	0	0					BUNCHER	1
8:02	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:02	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:02	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:02	LOADER		0					2		0	0	0	0	0	LOADER	
8:02	BUCKER		0					2		0	0	0	0	0	BUCKER	
8:03	FELL--1	1	3	0	0		0		0	51					FELLER	1
8:03	BUNCH-1	0					0	3	0	0					BUNCHER	1
8:03	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:03	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:03	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:03	LOADER		0					3		0	0	0	0	0	LOADER	
8:03	BUCKER		0					3		0	0	0	0	0	BUCKER	
8:04	FELL--1	1	3	0	1		0		0	51					FELLER	1
8:04	BUNCH-1	0					0	4	0	0					BUNCHER	1
8:04	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:04	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:04	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:04	LOADER		0					4		0	0	0	0	0	LOADER	
8:04	BUCKER		0					4		0	0	0	0	0	BUCKER	
8:05	FELL--1	1	3	0	1		0		5	51					FELLER	1
8:05	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:05	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:05	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:05	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:05	LOADER		0					5		0	0	0	0	0	LOADER	
8:05	BUCKER		0					5		0	0	0	0	0	BUCKER	

Continued

TIME		TO	TL	TI	TU	TP	GDT	WDT	TOTAL	VOL/C	VOLLEFT	VOLDONE	CUMGT	CUMDT		
8:06	FELL--1	1	1	0	0		0		0	120					FELLER	1
8:06	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:06	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:06	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:06	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:06	LOADER		0					6		0	0	0	0	0	LOADER	
8:06	BUCKER		0					6		0	0	0	0	0	BUCKER	
8:07	FELL--1	1	1	0	1		0		0	120					FELLER	1
8:07	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:07	SKID--1	5	0	0	0	0	1	1	0	0					SKIDDER	1
8:07	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:07	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:07	LOADER		0					7		0	0	0	0	0	LOADER	
8:07	BUCKER		0					7		0	0	0	0	0	BUCKER	
8:08	FELL--1	1	1	0	1		0		3	120					FELLER	1
8:08	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:08	SKID--1	5	0	0	0	0	1	2	0	0					SKIDDER	1
8:08	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:08	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:08	LOADER		0					8		0	0	0	0	0	LOADER	
8:08	BUCKER		0					8		0	0	0	0	0	BUCKER	
8:09	FELL--1	1	3	0	0		0		0	210					FELLER	1
8:09	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:09	SKID--1	5	0	0	0	0	1	3	0	0					SKIDDER	1
8:09	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:09	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:09	LOADER		0					9		0	0	0	0	0	LOADER	
8:09	BUCKER		0					9		0	0	0	0	0	BUCKER	
8:10	FELL--1	1	3	0	0		0		0	210					FELLER	1
8:10	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:10	SKID--1	5	0	0	0	0	1	4	0	0					SKIDDER	1
8:10	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:10	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:10	LOADER		0					10		0	0	0	0	0	LOADER	
8:10	BUCKER		0					10		0	0	0	0	0	BUCKER	

Figure 9.—A portion of the output from the first day of simulated operation for the example problem, showing the system status printed every 10 minutes.

DAY NO. 1 EXAMPLE PROBLEM -- SYSTEM 272

TIME		TO	TL	TI	TU	TP	GDT	WDT	TOTAL	VOL/C	VOLLEFT	VOLDONE	CUMOT	CUMDT		
8:00	FELL--1	1	0	0	0		0		0	0					FELLER	1
8:00	BUNCH-1	0					0	0	0	0					BUNCHER	1
8:00	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:00	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:00	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:00	LOADER		0					0		0	0	0	0	0	LOADER	
8:00	BUCKER		0					0		0	0	0	0	0	BUCKER	
8:10	FELL--1	1	3	0	0		0		0	210					FELLER	1
8:10	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:10	SKID--1	5	0	0	0	0	1	4	0	0					SKIDDER	1
8:10	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:10	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:10	LOADER		0					10		0	0	0	0	0	LOADER	
8:10	BUCKER		0					10		0	0	0	0	0	BUCKER	
8:20	FELL--1	1	2	0	0		0		0	156					FELLER	1
8:20	BUNCH-1	22					0	5	0	51					BUNCHER	1
8:20	SKID--1	5	0	0	0	0	1	14	0	0					SKIDDER	1
8:20	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:20	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:20	LOADER		0					20		0	0	0	0	0	LOADER	
8:20	BUCKER		0					20		0	0	0	0	0	BUCKER	
8:30	FELL--1	1	1	0	1		0		3	132					FELLER	1
8:30	BUNCH-1	22					0	0	0	469					BUNCHER	1
8:30	SKID--1	5	0	0	0	0	1	24	0	0					SKIDDER	1
8:30	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:30	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:30	LOADER		0					30		0	0	0	0	0	LOADER	
8:30	BUCKER		0					30		0	0	0	0	0	BUCKER	
8:40	FELL--1	1	1	0	1		0		3	61					FELLER	1
8:40	BUNCH-1	22					0	0	0	469					BUNCHER	1
8:40	SKID--1	5	0	0	0	0	1	34	0	0					SKIDDER	1
8:40	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:40	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:40	LOADER		0					40		0	0	0	0	0	LOADER	
8:40	BUCKER		0					40		0	0	0	0	0	BUCKER	
8:50	FELL--1	1	1	0	2		0		4	153					FELLER	1
8:50	BUNCH-1	16					0	0	0	413					BUNCHER	1
8:50	SKID--1	5	17	0	0	0	16	43	0	520					SKIDDER	1
8:50	HAUL--1	77	0	0	0		4	0	0	0					TRUCK	1
8:50	HAUL--2	84	0	0	0		3	0	0	0					TRUCK	2
8:50	LOADER		0					50		0	0	0	0	0	LOADER	
8:50	BUCKER		0					50		0	0	0	0	0	BUCKER	

Figure 10.—A portion of the output from the first day of simulated operation for the example problem, showing the system status printed every hour.

DAY NO. 1 EXAMPLE PROBLEM — SYSTEM 272

TIME		TO	TL	TI	TU	TP	GDT	WDT	TOTAL	VOL/C	VOLLEFT	VOLDONE	CUMOT	CUMDT		
8:00	FELL—1	1	0	0	0		0		0	0					FELLER	1
8:00	BUNCH-1	0					0	0	0	0					BUNCHER	1
8:00	SKID—1	5	0	0	0	0	1	0	0	0					SKIDDER	1
8:00	HAUL—1	77	0	0	0		4	0	0	0					TRUCK	1
8:00	HAUL—2	84	0	0	0		3	0	0	0					TRUCK	2
8:00	LOADER		0					0		0	0	0	0	0	LOADER	
8:00	BUCKER		0					0		0	0	0	0	0	BUCKER	
9:00	FELL—1	1	1	0	1		0		0	92					FELLER	1
9:00	BUNCH-1	16					0	0	0	413					BUNCHER	1
9:00	SKID—1	5	17	0	0	0	16	43	0	520					SKIDDER	1
9:00	HAUL—1	77	0	0	0		4	0	0	0					TRUCK	1
9:00	HAUL—2	84	0	0	0		3	0	0	0					TRUCK	2
9:00	LOADER		0					60		0	0	0	0	0	LOADER	
9:00	BUCKER		0					60		0	0	0	0	0	BUCKER	
10:00	FELL—1	1	1	0	1		0		3	67					FELLER	1
10:00	BUNCH-1	11					0	0	0	611					BUNCHER	1
10:00	SKID—1	1	30	0	0	0	0	0	0	364					SKIDDER	1
10:00	HAUL—1	77	11	0	0		4	28	0	520					TRUCK	1
10:00	HAUL—2	84	0	0	0		3	33	0	0					TRUCK	2
10:00	LOADER		0					109		0	0	520	11	0	LOADER	
10:00	BUCKER		0					9		0	0	520	8	103	BUCKER	
11:00	FELL—1	1	1	0	0		0		0	106					FELLER	1
11:00	BUNCH-1	12					0	0	0	296					BUNCHER	1
11:00	SKID—1	1	25	6	0	0	27	0	0	962					SKIDDER	1
11:00	HAUL—1	77	16	0	0		4	83	0	884					TRUCK	1
11:00	HAUL—2	84	0	0	0		3	93	0	0					TRUCK	2
11:00	LOADER		0					164		0	0	884	16	0	LOADER	
11:00	BUCKER		0					51		0	0	884	14	115	BUCKER	
12:00	FELL—1	1	2	0	1		6		10	180					FELLER	1
12:00	BUNCH-1	9					0	0	0	206					BUNCHER	1
12:00	SKID—1	3	18	0	0	0	24	0	0	797					SKIDDER	1
12:00	HAUL—1	77	36	115	0		20	111	0	2004					TRUCK	1
12:00	HAUL—2	84	2	0	0		3	151	0	228					TRUCK	2
12:00	LOADER		0					10		0	0	2232	38	192	LOADER	
12:00	BUCKER		0					8		0	0	2232	27	205	BUCKER	
1:00	FELL—1	1	1	0	0		0		0	106					FELLER	1
1:00	BUNCH-1	14					0	0	0	526					BUNCHER	1
1:00	SKID—1	3	18	4	0	0	55	0	0	797					SKIDDER	1
1:00	HAUL—1	77	36	115	0		50	111	0	2004					TRUCK	1
1:00	HAUL—2	84	2	0	0		33	181	0	228					TRUCK	2
1:00	LOADER		0					40		0	0	2232	38	222	LOADER	
1:00	BUCKER		0					38		0	0	2232	27	235	BUCKER	

Figure 11.—The output from the first day of simulated operation for the example problem showing the system status printed only once during the day.

DAY NO. 1 EXAMPLE PROBLEM -- SYSTEM 272

TIME		TO	TL	TI	TU	TP	GDT	WDT	TOTAL	VOL/C	VOLLEFT	VOLDONE	CUMOT	CUMDT	
8:00	FELL--1	1	0	0	0		0		0	0					FELLER 1
8:00	BUNCH-1	0					0	0	0	0					BUNCHER 1
8:00	SKID--1	5	0	0	0	0	1	0	0	0					SKIDDER 1
8:00	HAUL--1	77	0	0	0		4	0	0	0					TRUCK 1
8:00	HAUL--2	84	0	0	0		3	0	0	0					TRUCK 2
8:00	LOADER		0					0		0	0	0	0	0	LOADER
8:00	BUCKER		0					0		0	0	0	0	0	BUCKER

T I M E S U M M A R Y

WALK	FELL	BUCK	LIMB	DW	DF	DB	DL	DUM	TREES	F(DW)	F(DF)	F(DB)	F(DL)
98	147	0	161	0	25	0	72	0	94	0	8	0	12
106	271	0	411	0	155	0	584	0					

OUT	HOOK	SKID	UNHOOK	DO	DH	DS	DU	TREES	TURNS	F(DO)	F(DH)	F(DS)	F(DU)
20	242	42	19	33	115	11	0	63	13	5	11	6	0
48	4754	246	31	299	1867	25	0	331					

OUT	LOGS	HAUL	UNLOAD	DO	DL	DH	DU	CHAIN	TRIPS	F(DO)	F(DL)	F(DH)	F(DU)
161	90	226	10	7	0	15	0	6	2	2	0	2	0
12985	0	25546	52	25	0	173	0	18					

C O S T S U M M A R Y

EQUIPMENT		OPERATING TIME	OPERATING COST	DELAY TIME	DELAY COST	TOTAL TIME	TOTAL COST	VOLUME	COST/ MBF
FELLER	1	406	22.79	127	6.25	533	29.04	14420	2.01
BUNCHER	1	490	77.90	56	6.79	546	84.69	14210	5.96
SKIDDER	1	323	73.00	232	38.30	555	111.31	8954	12.43
TRUCK	1	232	31.01	161	13.57	393	44.58	2004	22.25
TRUCK	2	254	35.00	298	28.68	552	63.67	3139	20.28
LOADER		89	14.08	450	63.40	539	77.48	5143	15.07
BUCKER		106	0.91	423	1.79	529	2.70	8194	0.33
TOTALS		---	254.69	---	158.79	---	413.48	5143	80.40

COMPONENT	COLUMN HEADING			
	TO	TL	TI	TU
Felling	Walking between trees	Felling	Bucking in the woods	Limbing and topping
Bunching	Operating time/cycle	—	—	—
Skidding	Return to felling area	Hookup at felling area	Skidding to landing	Unhooking at landing
Hauling	Mill to landing	Loading	Landing to mill	Unloading
Loading	—	Operating time per cycle	—	—
Bucking	—	Operating time per cycle	—	—

Figure 12.—The meaning of certain column headings found in the output from T-H-A-T-S. All values are put in these columns in whole minutes for the current cycle.

standard deviation) very close to the input. Usually the difference, between actual and simulated, is less than ½ minute for both the average and standard deviation.

Empirical distributions are used for dbh, log diameter, and log length; and the use of these by the simulator results in tree and log volumes very close to the actual for the stand being harvested. Also, the volumes per cycle (for bunching, skidding, and hauling) are usually close to observations made on the actual logging operations.

The equations used in some of the felling, skidding, and bucking subroutines were developed from the same data we have used to test the simulator. Needless to say, they work quite well for these seven operations in Appalachia. Whether they would be adequate for other areas is difficult to say, because tests have not been conducted. However, new equations can be substituted easily without affecting the mechanics or performance of the simulator.

Equations used in the hauling subroutines (EMPTY and HAUL) were developed from data collected on entirely different logging operations, yet they have been satisfactory predictors for the seven operations used in testing T-H-A-T-S. Of course, they should be checked before extending their use to areas outside the Appalachian Region. Also, since they are representative of performance with tandem axle trucks, they may not be adequate for tractor-trailer rigs, etc.

Waiting delay time is a good indicator of system interaction; and since it is not a part of the input, it becomes a fairly good criteria for model validity. In collecting data on the seven operations, we coded all delay times as to whether they were self-caused or whether they accrued while waiting for other system components to finish a task. Waiting delays generated by a simulation run usually corresponded rather closely to the observed values. For example, the actual waiting delay time per skidding turn was 1½ minutes for system 272

(the system used as an example problem in this discussion). Using the time summary data generated at the completion of the run, we can compute the simulated average time spent waiting by the skidder:

Total delay time over 9 days = 1,747 minutes		
Less self-caused delay:		
Return trips	—	168 minutes
Hookup	—	933 minutes
Skidding	—	61 minutes
Unhooking	—	272 minutes
		1,434 minutes
Total waiting delay time = 313 minutes		

Averaging this total waiting delay time over 123 turns, we get 2.5 minutes per turn, which is only 1 minute greater than the observed value.

The methodology of the model and its structure need little validation because the simulator simply duplicates the process of logging as it is normally performed in Appalachia. The sequence of operations is the same in both.

CONCLUSION

This paper was designed to provide the information needed for using T-H-A-T-S to analyze a logging system. Although the present subroutines make it peculiar to the Appalachian Region, the simulator is sufficiently flexible to be adapted for use with most logging operations.

Simulation is an invaluable aid to the decision-maker because for the first time he is able to see what effects a proposed change will have on his entire system. T-H-A-T-S is no cure-all, but it can provide new insight into the workings of a logging system, and at a price the manager can well afford to pay.

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APPENDIX

A. COMPUTER COMPATIBILITY

T-H-A-T-S is programmed in FORTRAN IV and has been successfully run on an IBM System/370 computer. It should perform equally well with any large computing hardware. Although the program is quite large in terms of source statements, the amount of array storage needed is relatively small (only 2.5K). Consequently, total core storage required is less than 175K.

When the program is to be run, it may be necessary to change the logical unit numbers for the READ and WRITE statements. The IBM system that was used required a 5 for input from cards and a 6 for printed output. To change these values, the user must repunch the first two statements that follow the DIMENSION statement, LUI = 5 and LUO = 6. LUI is the logical unit number for the READ statements, and LUO corresponds to WRITE statements.

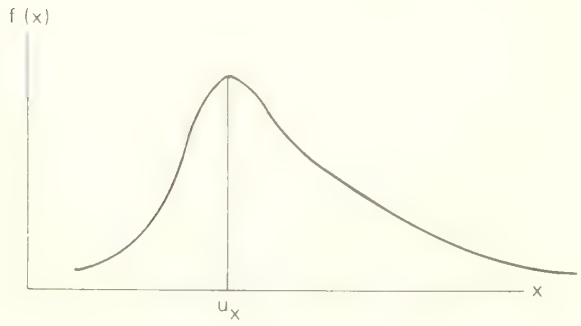
B. NORMAL AND LOGNORMAL DISTRIBUTIONS

Although subroutine RANDU provides random numbers whenever needed, in most cases the value generated by the simulator must be more than random; it must correspond to a specified distribution. That is, it must be a random variable, not just a random number.

Simulated times are generated by T-H-A-T-S from one of two subroutines. Subroutine NORMAL is based on the normal distribution, subroutine LOGNOR on the lognormal distribution.

The lognormal distribution, which is employed by most of the subroutines in the present version of T-H-A-T-S, is explained as follows (*Naylor et al. 1966, p. 99*):

> If the logarithm of a random variable has a normal distribution, the random variable has a positively skewed continuous distribution known as the lognormal distribution.
>
> In other words, if the data were distributed this way—it was concluded that a lognormal distribution (and subroutine LOGNOR) should be more appropriate for generating the simulated values than the normal distribution. And after considerable testing with the simulator, the conclusion was verified; "better" values were generated by LOGNOR for those variables having the skewed distribution.



The lognormal distribution is used for all delay times and for most operating times. It was found that those times having an expected value close to zero were nearly always lognormally distributed. Hauling times are generated from a normal distribution, as is bunching time and merchantable height of each felled tree.

Of course, the user may very easily change this procedure should he find that his data behave differently from our Appalachian findings. The "CALLS" to LOGNOR may be changed to NORMAL and vice versa, because the inputs to each routine are the same. More details about the subroutines can be found in Naylor et al. (*1966*).

C. COMPUTER COSTS

Although T-H-A-T-S is a rather complex program, it is quite economical to use. For example, four separate runs were made with the data for our illustrative problem (parts of the output appear as figures 8, 9, 10, and 11); and the costs, using an IBM system/370 computer located on a university campus, were as follows:

• A 10-day run with status-printing only once during each day	$ 8.92
• A 10-day run with status-printing each hour	10.08
• A 1-day run with status-printing every 10 minutes	7.22
• A 1-day run with status-printing every minute	11.60

Obviously, computer processing charges vary from place to place; therefore, these figures should serve as a guide only. To assess the magnitude of computer costs, the user should run one or more of the versions used for the example problem. Then, based on the actual expense, he or she would be able to predict the costs of future runs in the following manner.

1. Run the example problem at your computer center.
2. Compute the variable costs of the run (VCC_o) = total costs − fixed costs. The fixed costs will normally be such items as charges for card input, channel time, printing messages, etc.
3. Compute the variable cost per machine-day (VCPMD) as follows:
   $VCPMD = VCC_o \div MD_o$
   Where: MD_o = The number of machine-days in the example problem.
   = 7 machines times 10 days.
   = 70
4. For any other computer run having the same printing frequency, estimate the costs as follows:
   a. Compute the appropriate number of machine-days for the new run.
      MD_n = Number of machines times expected number of days.
   b. Estimate variable costs for the new run.
      $VCC_n = MD_n$ times VCPMD
   c. Estimate total cost of the new run.
      Total cost = fixed costs + VCC_n

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1975. **T-H-A-T-S—Timber Harvesting And Transport Simulator.** NE. For. Exp. Stn., Upper Darby, Pa.
31 p., illus. (USDA Forest Serv. Res. Pap. NE-316)

A detailed description of a FORTRAN IV computer program for simulating a typical timber-harvesting operation. Designed as a user's manual, the paper contains program development and operation, instructions for use, and output from an example problem. Flow charts are also included.

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An Evaluation of
TREES and SHRUBS
for Planting Surface-Mine Spoils

by William T. Plass

USDA FOREST SERVICE RESEARCH PAPER NE-317
1975

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MANUSCRIPT RECEIVED FOR PUBLICATION 12 MAY 1974

An Evaluation of TREES and SHRUBS for Planting Surface-Mine Spoils

ABSTRACT

Fifty-five tree and shrub species were evaluated on two surface-mine sites in eastern Kentucky. After 4 years' growth, comparison of survival and growth was used to identify the promising species for planting on acid surface-mine spoils. Three species of birch and three *Eleagnus* species survived and grew well on a range of sites. Noncommercial tree species and shrubs adapted to acid surface-mine spoils included silktree, tree-of-heaven, French tamarisk, Japanese fleeceflower, and Amur privet.

FIELD TRIALS HAVE suggested the suitability of many tree species for the reforestation of surface-mine spoils (*1, 2, 3, 4, 5, 6, 7*). Results from these trials have provided guidelines for selecting appropriate species for specific sites—usually tree species that would produce forest products with tangible commercial value. Species with little or no commercial value have seldom been included in these evaluations.

Today more emphasis is placed on site protection. There is a need for vegetation that will rapidly develop a protective cover as well as species that will provide long-term site protection. Trees and shrubs that will grow rapidly on a broad range of site conditions have become as important as species with commercial value.

In addition to site protection, more consideration is now being given to species that will enrich the soil and provide food and cover for wildlife. Soil enrichment is necessary for continued site protection, and wildlife plantings are becoming more important as pressures for recreation uses of the land increase.

Fifty-five tree and shrub species were evaluated in this study to determine their survival and growth on acid surface-mine spoils. These species provide one or more of the following benefits: potential economic value, wildlife food and cover, soil enrichment by nitrogen fixation, and aesthetic amelioration. Species showing rapid growth on a variety of site conditions are considered most attractive for surface-mine revegetation. The results of this evaluation help us to identify tree and shrub species that deserve expanded use on areas disturbed by surface-mining.

STUDY DESCRIPTION

A total of 28 tree species and 27 shrub species seldom planted on surface-mined sites were evaluated (tables 1 and 2). Planting stock was obtained from private, state, and federal nurseries. Selections from available stock were based on published and unpublished information from surface-mine-spoil plantings; literature on the geographic range of the plant; and references indicating the suitability of specific plants to acid and drastically disturbed sites. There was little informaion about some species, but interpretation of the available facts indicated possible survival on surface-mine spoils. For example, acid soils are required for the production of blueberries.

The study was established at two locations in Kentucky. Site 1 is located near London, Kentucky. Site 2 is located west of Middlesboro, Kentucky. The elevations at these sites are between 1,000 and 1,500 feet above sea level.

At each site, 12 blocks were planted to trees, and 12 blocks were planted to shrubs. Within each block, one species was randomly assigned to a 6-x-6-foot plot. Four seedlings spaced 3 x 3 feet apart were planted in each plot. Therefore, the evaluation of many species was based upon 96 seedlings planted in 24 plots at two sites. For some species, only a small number of seedlings were available. Seedlings for these species were planted on one site in as many blocks as possible. All stock was bare-rooted except rhododen-

Table 1.—Trees evaluated

Scientific name[1, 2]	Common name[3]
COMMERCIALLY IMPORTANT	
Abies fraseri Poir.	Fraser fir
Betula lenta L.	Sweet birch
Betula lutea Michx.	Yellow birch
Betula pendulata Roth.	European white birch
Thuja occidentalis L.	White cedar
Magnolia acuminata L.	Cucumbertree
Nyssa sylvatica Marsh.	Blackgum
Pinus nigra Arnold.	Austrian pine
Pinus thunbergi Parl.	Japanese black pine
Quercus coccinea Muenchh.	Scarlet oak
Quercus macrocarpa Michx.	Bur oak
Quercus palustris Muenchh.	Pin oak
Quercus serrata Thumb.	Sawtooth oak
Tilia cordata Mill.	Littleleaf linden
NONCOMMERCIAL OR ORNAMENTAL	
Acer negundo L.	Boxelder
Ailanthus altissima Swingle.	Tree-of-heaven
Albizia julibrissin Durazz.	Silktree
Gleditsia triacanthos inermis Purch.	Thornless honeylocust
Morus alba tatarica Seringe.	Russian mulberry
Morus nigra L.	Black mulberry
Oxydendrun arboreum DC.	Sourwood
Sophora japonica L.	Japanese pagodatree
Ulmus pumila L.	Siberian elm
TALL SHRUB OR SMALL TREES	
Caragana arborescens Lam.	Siberian peashrub
Cornus florida L.	Flowering dogwood
Cotinus obovatus Raf.	American smoketree
Crataegus spp.	Hawthorn
Tamarix gallica L.	French tamarisk

[1] Little, Elbert L., Jr. Check list of native and naturalized trees of the United States. U.S. Dep. Agric. Handb. 41. 471 p. 1953.

[2] Fernald, Merritt L. Gray's manual of botany. Ed. 8, 1631 p. American Book Company. 1950.

[3] Kelsey, Harlan P., and William A. Dayton. Standardized plant names. 675 p. J. Horace McFarland Company. 1942.

Table 2.—Shrubs evaluated

Scientific name[1, 2]	Common name[3]
4 TO 6 METERS TALL	
Amorpha fruticosa L.	Indigobush
Cephalanthus occidentalis L.	Common buttonbush
Cotoneaster acutifolia Turez.	Peking cotoneaster
Elaeagnus angustifolia L.	Russian olive
Elaeagnus pungens Thumb.	Thorny olive
Elaeagnus umbellata Thumb.	Autumn olive
Ligustrum amurense Carr.	Amur privet
Ligustrum sinense Lour.	Chinese privet
Lonicera korolkowi zabeli Rehd.	Blueleaf honeysuckle
Syringa chinensis Willd.	Chinese lilac
Viburnum dentatum L.	Arrow-wood viburnum
1 TO 3 METERS TALL	
Berberis vulgaris L.	European barberry
Cornus amomum Mill.	Silky dogwood
Cytisus scoparius Lk.	Scotch broom
Elaeagnus multiflora Thumb.	Cherry olive
Hibiscus syriacus L.	Shrub-althea
Hydrangea quercifolia Bartr.	Oakleaf hydrangea
Lonicera tartarica L.	Tartarian honeysuckle
Polygonum cuspidatum Sieb. & Zucc.	Japanese fleeceflower
Prinsepia sinensis Oliver.	Cherry prinsepia
Rhododendron catawbiense Michx.	Catawba rhododendron
Symphoricarpus orbiculatus Moench.	Coralberry
Vaccinium spp.	Blueberry
TRAILING STEMS	
Rosa multiflora Thumb.	Multiflora rose
Rosa rugosa Thumb.	Rugosa rose
Rubus spp.	Dewberry
Rubus spp.	Blackberry

[1] Little, Elbert L., Jr. Check list of native and naturalized trees of the United States. U.S. Dep. Agric. Handb. 41. 471 p. 1953.

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dron, which was packed and planted with a small ball of nursery soil around the roots.

Plot size was designed to minimize spoil differences between planting holes and to simplify spoil-sampling procedures. After the seedlings were planted, a sample of surface spoil was collected from the center of each plot. Standard laboratory procedures were used to determine pH and total soluble salts. Available phosphorus was determined by the Bray No. 1 method.

At the end of the fourth growing season, species survival was determined, and the total height of each living plant was measured to the nearest tenth of a foot. Height measurements for all species represent the distance from the ground line to the tip of the longest branch when fully extended. This procedure was adopted because the growth forms of the species varied.

SPOIL CHARACTERISTICS AT PLANTING SITES

The spoils at Site 1 are predominantly gray and black shales, which had a pH of 4.5 or less at the time of establishment (table 3). Forty percent of all samples collected had a total soluble-salt concentration of 0.50 mmhos/cm or less (table 4). Available phosphorus was low to very low (less than 7 ppm) in about 60 percent of the samples (table 5). The spoil was less than a year old when planted. All blocks were established on relatively flat, graded portions of the disturbed area.

Table 3.—Distribution of spoils by pH classes, in percent

pH class	Shrub blocks		Tree blocks	
	Site 1	Site 2	Site 1	Site 2
2.6 to 3.5	27.2	16.2	18.1	15.3
3.6 to 4.5	68.1	36.8	72.3	40.2
4.6 to 5.5	4.0	0.6	9.2	1.5
5.6 to 6.5	.7	2.8	.4	2.9
6.6 to 7.5	—	25.7	—	25.9
7.6 to 8.5	—	17.9	—	14.2

Table 4.—Distribution of spoils by total soluble-salt classes, in percent

Soluble-salt class (mmhos/cm)	Shrub blocks		Tree blocks	
	Site 1	Site 2	Site 1	Site 2
0.01 to 0.25	38.6	76.9	43.3	72.8
0.26 to 0.50	48.6	21.1	49.6	23.7
0.51 to 0.75	7.1	1.7	4.9	1.0
0.76 to 1.00	2.7	.3	1.6	1.3
1.01 +	3.0	—	.6	1.2

Table 5.—Distribution of spoils by available-phosphorus classes, in percent

Available-phosphorus class (ppm)	Shrub blocks		Tree blocks	
	Site 1	Site 2	Site 1	Site 2
0 to 3	23.7	93.0	16.1	96.3
4 to 6	38.8	6.2	39.1	3.1
7 to 9	26.1	.4	27.6	.6
10 to 12	8.6	.4	13.8	—
13 to 15	2.1	—	3.4	—
16 to 18	.7	—	—	—

At Site 2, the spoil was a mixture of sandstone and shale having a brown to gray color. Half of the blocks were established on extremely acid spoil that had a pH of 4.5 or less. The other blocks had spoils with near-neutral to slightly alkaline reaction. All spoils had a very low soluble-salt concentration. Seventy-five percent had concentrations of 0.25 mmhos/cm or less. Available phosphorus was very low (3 ppm or less) at 95 percent of the sample points. The spoil was less than a year old. All blocks were established on a regraded bench.

The variation in site characteristics between Sites 1 and 2 and the extremes within Site 2 permitted comparisons of survival and growth with pH and phosphorus values. For these evaluations, the acid spoils of Site 2 were designated Site 2-A; and the neutral to slightly alkaline spoils were referred to as Site 2-B.

RESULTS

Tree Species

The 28 species of trees were grouped into three classes: (1) commercially important; (2) noncommercial or ornamentals; and (3) species that could be classified either as tall shrubs or as small trees. For each species, survival and total height were computed by sites and for both sites combined.

Silktree, thornless honey locust, and hawthorn had the highest survival rates for those species planted on both sites (table 6). Scarlet oak planted on three plots on Site 2 survived well. Siberian elm and French tama-

Table 6.—Survival of tree species, in percent

Species	Site 1	Site 2	Both Sites
COMMERCIALLY IMPORTANT			
Scalet oak	*	85	85
Littleleaf linden	40	46	42
Pin oak	42	40	41
White cedar	*	40	40
Yellow birch	35	44	40
Sweet birch	40	40	40
Sawtooth oak	*	33	33
Bur oak	29	27	28
White birch	35	17	26
Austrian pine	29	4	17
Blackgum	6	14	10
Japanese black pine	8	4	6
Fraser fir	0	6	3
Cucumbertree	0	2	1
NONCOMMERCIAL OR ORNAMENTAL			
Silktree	94	75	84
Thornless honeylocust	75	68	72
Siberian elm	67	33	51
Tree-of-heaven	46	54	50
Japanese pagodatree	29	69	49
Boxelder	21	35	28
Black mulberry	25	5	15
Sourwood	15	14	14
Russian mulberry	17	0	9
TALL SHRUBS OR SMALL TREES			
Hawthorn	56	64	62
French tamarisk	71	20	48
Siberian peashrub	44	46	45
American smoketree	21	4	13
White dogwood	13	6	10

* This species was not planted on this site.

risk survived well on Site 1. On Site 2, Japanese pagodatree ranked third in survival.

Japanese black pine, blackgum, Fraser fir, cucumbertree, Russian mulberry, and white dogwood had very low overall survival rates. Survival of Austrian pine, black mulberry, and American smoketree was low; but it was better on Site 1, which had more phosphorus and soluble salts.

Rapid growth is considered an advantage for site protection and yield. Of all tree species evaluated, European white birch made the most rapid growth (table 7). It grew equally well on both sites. French tamarisk, silktree, sweet birch, and yellow birch were ranked next in overall growth.

Cucumbertree and Fraser fir were definitely off-site, and grew very slowly. Sourwood, Japanese pagodatree, blackgum, and American smoketree grew slowly and could not be considered suitable trees for site protection.

Seven species ranked high in both survival and growth were used for comparison of tree response to selected chemical characteristics of the spoil. Two variables, pH and phosphorus, were used. Soluble salts were low on

Table 7.—Mean total height of tree species after four growing seasons, in feet

Species	Site 1	Site 2	Both Sites
COMMERCIALLY IMPORTANT			
White birch	8.5	8.1	8.4
Yellow birch	4.5	3.7	4.1
Sweet birch	4.3	3.7	4.0
Pin oak	3.5	6.5	3.8
Scarlet oak	—	3.5	3.5
Sawtooth oak	—	3.2	3.2
Japanese black pine	2.5	3.0	2.7
White cedar	—	2.4	2.4
Bur oak	2.6	1.9	2.3
Austrian pine	2.0	.7	1.8
Littleleaf linden	1.2	2.0	1.6
Blackgum	1.8	1.4	1.5
Cucumbertree	—	.5	.5
Fraser fir	—	.5	.5
NONCOMMERCIAL OR ORNAMENTAL			
Silktree	5.7	4.0	4.9
Tree-of-heaven	3.9	5.8	3.8
Siberian elm	3.2	4.2	3.5
Boxelder	2.7	4.4	2.8
Black mulberry	3.6	3.3	2.7
Russian mulberry	2.4	—	2.4
Thornless honeylocust	2.4	2.2	2.3
Japanese pagodatree	1.2	1.7	1.4
Sourwood	.8	1.6	1.2
TALL SHRUB OR SMALL TREE			
French tamarisk	6.0	11.0	7.0
White dogwood	2.1	3.6	2.4
Hawthorn	2.4	2.1	2.2
Siberian peashrub	1.5	2.4	2.0
American smoketree	1.8	.4	1.6

Table 8.—Mean height and survival of tree species, by site

Species	Site	Mean height	Survival	Site characteristics		
				pH	Soluble salts	P
		Feet	*Pct.*	*pH*	*mmhos/cm*	*ppm*
White birch	1	8.6	35	3.8	0.298	5.8
	2-A	8.4	21	3.8	.166	.9
	2-B	5.9	13	7.1	.210	1.9
Yellow birch	1	4.5	35	4.1	.267	8.1
	2-A	5.0	50	3.8	.197	1.9
	2-B	6.1	50	7.4	.319	2.2
Sweet birch	1	5.9	40	4.1	.248	8.6
	2-A	2.7	25	3.8	.171	1.1
	2-B	2.5	54	7.4	.175	1.8
Pin oak	1	3.5	42	3.8	.293	6.4
	2-A	3.3	38	3.9	.215	1.9
	2-B	1.6	44	7.6	.196	1.5
Silktree	1	5.7	94	4.3	.243	8.1
	2-A	3.8	68	4.0	.209	2.2
	2-B	4.5	80	7.1	.205	1.6
Tree-of-heaven	1	3.9	46	4.2	.245	8.8
	2-A	3.8	43	4.1	.249	1.8
	2-B	3.1	70	7.5	.160	2.9
French tamarisk	1	6.0	71	4.1	.359	8.4
	2-A	—	0	3.7	.264	1.3
	2-B	8.7	60	7.3	.211	2.7

all sites and probably did not influence survival or growth.

The plots on Site 2 were subdivided into two groups for these comparisons. Site 2-A included plots having low pH and very low phosphorus. The Site 2-B plots were characterized by high pH and very low phosphorus. Tree growth on these two plots was compared to the survival and growth on all plots on Site 1. The Site 1 plots had low pH and low phosphorus.

Sweet birch and silktree made their best growth on Site 1. This site was characterized by a pH around 4.0, and by 6 to 8 ppm phosphorus. These same species made slower growth and had lower survival on Site 2-A. The Bray No. 1 test indicated about one-fourth as much phosphorus in the Site 2-A spoil as in the Site 1 spoils.

On Site 2-B, which was characterized by a pH of 7 to 8 and 1 to 3 ppm phosphorus, European white birch, sweet birch, pin oak, and silktree made their slowest growth. Yellow birch and French tamarisk had high survival and grew well on this site. The growth of tree-of-heaven was similar on all sites, but survival was best on Site 2-B (table 8).

Shrub Species

Many shrub species are characteristically low-growing plants that range widely in stem form. These were grouped by the following height classes: (1) maximum height 4 to 6 meters; (2) maximum height 1 to 3 meters; and (3) species with trailing stems. The survival and total height of each shrub species were computed for individual sites and for both sites combined.

Thorny olive and Japanese fleeceflower had the highest survival on both sites (table 9). Indigobush planted on Site 1 and buttonbush planted on Site 2 had high survival, but their adaptability to different site conditions could not be determined. These species should be evaluated in future studies.

Arrow-wood viburnum, blueleaf honeysuckle, Russian olive, cherry prinsepia, scotch broom, and all of the shrubs with trailing stems had very low survival. The use of these species on sites with similar characteristics should be discouraged because they have no specific advantage over other species.

Growth of autumn, thorny, and cherry olive was better than that of many other shrubs (table 10). Russian olive may not be adapted to these sites because only a few plants survived on the neutral spoils on Site 2. Japanese fleeceflower and multiflora rose grew well and had higher survival and growth on Site 1.

Species that grew very slowly were blueberry, Catawba rhododendron, cherry prinsepia, and rugosa rose. These probably would provide little site protection after 4 years' growth on acid surface-mine spoils.

Growth and survival were used to identify species poorly adapted to acid sites. On this basis, Chinese lilac, blueleaf honeysuckle, cherry prinsepia, Catawba rhododendron, dewberry, blackberry, and rugosa rose were judged to be least suited to these sites.

Seven species ranked high in both survival

Table 9.—Survival of shrubs, in percent

Species	Site 1	Site 2	Both sites
4 TO 6 METERS TALL			
Indigobush	90	*	90
Common buttonbush	*	83	83
Thorny olive	65	90	76
Peking cotoneaster	64	38	51
Autumn olive	54	42	48
Amur privet	42	38	40
Chinese privet	44	6	29
Chinese lilac	6	43	24
Arrow-wood viburnum	10	18	14
Blueleaf honeysuckle	15	3	9
Russian olive	0	14	7
1 TO 3 METERS TALL			
Japanese fleeceflower	96	66	80
Coralberry	65	55	60
Cherry olive	44	56	50
European barberry	40	48	43
Blueberry	27	60	42
Silky dogwood	40	25	34
Catawba rhododendron	19	40	28
Shrubalthea	15	41	27
Tartarian honeysuckle	38	15	26
Oakleaf hydrangea	21	25	23
Cherry prinsepia	*	17	18
Scotch broom	8	0	4
TRAILING STEMS			
Rugosa rose	19	14	16
Blackberry	14	13	14
Multiflora rose	14	4	11
Dewberry	11	6	9

* This species was not planted on this site.

Table 10.—Mean total height of shrubs species after four growing seasons, in feet

Species	Site 1	Site 2	Both sites
4 TO 6 METERS TALL			
Autumn olive	5.3	5.5	5.4
Russian olive	—	4.9	4.9
Thorny olive	3.3	5.3	4.5
Amur privet	3.0	3.6	3.3
Common buttonbush	—	2.9	2.9
Indigobush	2.4	—	2.4
Peking cotoneaster	2.0	2.6	2.2
Arrow-wood viburnum	2.2	2.0	2.1
Blueleaf honeysuckle	1.6	4.2	2.0
Chinese privet	2.0	1.0	1.9
Chinese lilac	2.1	1.8	1.9
1 TO 3 METERS TALL			
Cherry olive	3.5	5.1	4.4
Japanese fleeceflower	4.8	3.7	4.3
Scotch broom	3.4	—	3.4
Silky dogwood	2.5	3.6	2.8
Shrubalthea	2.3	2.7	2.6
Tartarian honeysuckle	2.2	2.9	2.4
Oakleaf hydrangea	2.2	2.5	2.4
Coralberry	1.3	2.8	2.0
European barberry	1.4	1.6	1.5
Blueberry	1.3	1.4	1.4
Catawba rhododendron	1.1	.9	1.0
Cherry prinsepia	—	.8	.8
TRAILING STEMS			
Multiflora rose	5.5	.6	4.9
Dewberry	3.7	.8	2.8
Blackberry	2.4	1.1	1.8
Rugosa rose	1.4	1.3	1.4

and growth, and these were used for comparisons of shrub response to selected chemical characteristics of the spoil. Two variables, pH and phosphorus, were used. Soluble salts were low on all sites and probably did not influence survival or growth.

The plots on Site 2 were subdivided into two groups for these comparisons. Site 2-A included plots having low pH and very low phosphorus. Site 2-B plots were characterized by high pH and very low phosphorus. Shrub growth on these two plots was compared to the survival and growth on all plots on Site 1. The Site 1 plots had low pH and low phosphorus.

All species except Japanese fleeceflower made their best growth on Site 2-B (table 11). This site was characterized by high pH and very low phosphorus. Survival of autumn olive, thorny olive, cherry olive, Amur privet, and coralberry was higher on Site 2-B and lowest on Site 2-A.

Comparisons of growth and survival for these seven species by site indicate important trends. Six of the seven species made their best growth on spoils of high pH and

Table 11.—Mean height and survival of shrub species, by site

Species	Site	Mean height	Survival	Site characteristics		
				pH	Soluble salts	P
		Feet	*Pct.*	*pH*	*mmhos/cm*	*ppm*
Autumn olive	1	5.4	54	3.6	0.273	4.4
	2-A	3.1	17	4.2	.461	2.7
	2-B	6.1	67	6.8	.231	1.8
Thorny olive	1	4.4	65	3.8	.322	6.6
	2-A	5.7	63	3.8	.241	1.1
	2-B	7.8	100	7.2	.155	2.7
Japanese fleeceflower	1	4.8	96	4.4	.186	6.9
	2-A	3.2	71	3.8	.207	2.2
	2-B	4.0	63	7.3	.177	1.1
Cherry olive	1	3.5	44	3.9	.269	8.5
	2-A	2.6	38	3.7	.207	1.5
	2-B	6.4	75	7.0	.195	1.7
Silky dogwood	1	2.5	40	3.9	.288	6.0
	2-A	2.5	8	4.4	.188	6.6
	2-B	3.7	13	7.4	.170	.9
Amur privet	1	3.0	42	3.7	.357	6.8
	2-A	2.7	29	3.9	.211	2.9
	2-B	4.4	50	7.4	.155	1.6
Coralberry	1	1.3	65	3.7	.334	5.9
	2-A	2.2	42	4.0	.217	2.8
	2-B	3.1	88	7.5	.163	5.2

very low phosphorus. Survival of three of these same species was highest on the same spoil. Japanese fleeceflower was the only species that had high survival and grew well on the acid low-phosphorus Site 1. Low survival and slow growth characterized silky dogwood on all sites.

CONCLUSIONS

In this study several species of trees and shrubs that are adapted to planting on acid surface-mine sites were identified. Species least suited to the spoils on the experimental sites were also identified.

Three species of birch ranked high in survival and growth. European white birch and sweet birch were adapted to low pH spoils, while yellow birch grew best on the neutral spoils. It is believed that these as well as other species of birch should be grown in nurseries supplying stock for surface-mine reforestation. Additional research will be required to determine for each species the site requirements and growth on a range of spoil conditions.

Pin oak ranked high in survival and growth. Scarlet oak grew well on a few plots characterized by acid spoils. This raises a question about the suitability of other species from the red oak group for spoil-bank reforestation. Northern red oak (*Quercus rubra* L.) is used extensively for surface-mine reforestation. It is possible that black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.), pin oak, (*Quercus palustris* Muenchh.), and other red oaks may also he desirable for surface-mine reforestation.

Silktree, tree-of-heaven, and French tamarisk are species of little or no commercial value that survived and grew well on both sites. French tamarisk was better adapted to the neutral spoils, and silktree and tree-of-heaven to the more acid spoils having low to moderate phosphorus. Silktree is a legume, and would serve as a soil builder and nurse crop for commercially valuable tree species. Tree-of-heaven and French tamarisk would be useful for site protection and aesthetics.

The excellent survival and growth of three of the four species of *Eleagnus* indicate that the genus is well adapted to a range of spoil conditions. Autumn olive is widely used for site protection and as a wildlife food plant, but other species of olive may be as effective on some sites.

Silky dogwood and coralberry are promising wildlife food shrubs. Coralberry survived well on a range of sites, but grew best on the neutral spoils. Silky dogwood grew well on the neutral spoils, but survival was poor on all sites.

Fleeceflower and Amur privet are adapted to a range of sites. These species have little value except for site protection and aesthetics.

False indigo and buttonbush should be considered in future evaluations. Both survived and grew well on acid sites. False indigo is a legume, and both are considered attractive wildlife shrubs.

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8 p. (USDA For. Serv. Res. Pap. NE-317)

Fifty-five trees and shrub species were evaluated on two surface-mine sites in eastern Kentucky. After 4 years' growth, comparison of survival and growth was used to identify the promising species for planting on acid surface-mine spoils. Three species of birch and three *Elcagnus* species survived and grew well on a range of sites. Noncommercial tree species and shrubs adapted to acid surface-mine spoils included silktree, tree-of-heaven, French tamarisk, Japanese fleeceflower, and Amur privet.

OXFORD: 232.11:114.449.8. **KEY WORDS:** surface-mining, acid spoils, tree species, shrub species.

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A Photographic Technique to Estimating Egg Density of the White Pine Weevil, Pissodes strobi (Peck)

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The Author

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A Photographic Technique for Estimating Egg Density of the White Pine Weevil, Pissodes strobi (Peck)

ABSTRACT

Compares a photographic technique with visual and dissection techniques for estimating egg density of the white pine weevil, *Pissodes strobi* (Peck). The relatively high correlations (.67 and .79) between counts from photographs and those obtained by dissection indicate that the non-destructive photographic technique could be a useful tool for determining egg density.

INTRODUCTION

The white pine weevil, *Pissodes strobi* (Peck) is a major pest of coniferous trees in the northeastern United States, causing losses of several million dollars annually. Its major hosts are eastern white pine, (*Pinus strobus* L.), pitch pine, (*Pinus rigida* Mill.), Jack pine (*Pinus banksiana* Lamb.), and red spruce, (*Picea rubra* Link.)

Life-table data on this insect are being collected to improve our understanding of its population dynamics and facilitate its control. Several methods of gathering these data have been used (Waters and McIntyre 1953; Marty and Mott 1964; Ford, Talerico, and Mott 1965). These methods were based either on counts of adult weevils or on the number of weeviled leaders in a stand. Adult populations can also be predicted from egg-stage measurements, but determining egg density is time-consuming, expensive, and destructive. It requires removing the leader from a tree and examining it under a dissecting microscope to count the egg holes, or dissecting it to determine the actual number of eggs present. This study was designed to evaluate a rapid, nondestructive photographic technique for determining egg density.

METHODS

Field Procedures

The study was conducted during the spring and summer of 1971 in a mixed white pine and larch plantation in Cheshire, Conn. Forty white pines 2 to 7 feet in height, and showing signs of either oviposition or extensive feeding, were selected for study.

All needles were removed from the leaders of 20 trees; the other 20 trees were left unaltered. The leaders were marked with white enamel on the east, north, west and south sides. Each week five trees with deneedled leaders (fig. 1) and five trees with unaltered leaders (fig. 2) were selected for study. Leaders were photographed in the field, then cut and taken to the laboratory for study and dissection.

Figure 1.—Signs of fresh feeding on a leader with needles removed.

Figure 2.—Unaltered leader.

Photographic Technique

The photographic equipment and techniques used to obtain the photographs are outlined in an unpublished office report on file at the Forest Insect and Disease Laboratory at Hamden, Connecticut.

Laboratory Procedures

Egg holes were first counted from the 35mm transparencies and recorded by section and compass quadrant. Then 50mm sections, beginning just below the new growth, were marked on the leaders, using landmarks such as needle fascicles that appeared in the transparencies. Under a dissecting microscope, egg holes visible in each section and quadrant were counted. Then the leaders were dissected to obtain an exact count of eggs present.

RESULTS AND DISCUSSION

A comparison of these egg counts is shown in table 1. The number of egg holes counted on the photographs for the deneedled leaders was 1202 as compared to 1037 counted visually. The actual number of eggs found was 1126. On the unaltered leaders the hole count from photographs was 305, the visual hole count was 463 and the actual number of eggs found on dissection was 513.

Linear regression analysis was used to compare these egg-counting techniques: the results are shown in table 2. The total number of eggs found on all the deneedled leaders did not differ significantly from the hole counts made from photographs or visually, but individual counts were highly variable. The correlation between the photo counts and dissection counts in both the deneedled and unaltered leaders ranged from .7 to .8, but the standard deviation ranged from 20 to 25. Although this amount of variation may be unacceptable for some applications, the data indicate that the photo technique would be useful where nondestructive sampling is required.

The highest correlations were between egg hole counts made under the dissecting microscope and actual numbers of eggs found by dissection (.96 to .82).

Table 1.—Holes and eggs counted on white pine leaders from photographs, visually, and by dissection

Deneedled leaders				Unaltered leaders			
Leader number	Photo (holes)	Visual (holes)	Dissect (eggs)	Leader number	Photo (holes)	Visual (holes)	Dissect (eggs)
1	64	44	31	18	15	43	57
2	41	34	49	19	9	20	22
3	70	77	67	20	25	23	28
4	46	24	30	21	9	8	7
5	30	27	44	22	40	71	79
6	45	28	28	23	35	44	49
7	16	13	19	24	25	39	49
8	28	16	23	25	20	17	21
9	65	66	80	26	53	100	106
10	53	51	71	27	25	52	51
11	69	56	57	28	49	46	44
12	62	58	84	—	—	—	—
13	65	55	47	—	—	—	—
14	75	66	53	—	—	—	—
15	205	127	129	—	—	—	—
16	83	153	154	—	—	—	—
17	185	142	160	—	—	—	—
Total	1,202	1,037	1,126	Total	305	463	513

Twelve leaders were not examined because growth of saprophytic fungi made landmarks and egg and feeding holes unrecognizable.

Table 2.—Regression analysis of hole and egg counts by different methods

Statistic	Unaltered leaders		Deneedled leaders	
	Photo-dissection	Visual-dissection	Photo-dissection	Visual-dissection
Intercept	14.9303	.9134	17.3401	5.8597
Slope	1.1824	.9786	.6915	.9897
r	.6765	.8245	.7958	.9621
Standard deviation	19.7349	16.2603	25.6456	11.5555

The highest correlation between egg hole counts made from transparencies and actual egg numbers was in the leaders with needles removed (.79). Although the surface of the leader was not obscured by needles, any scars, feeding punctures or imperfections increased the counting error and, as a result, the standard deviation was high.

The lowest correlation between egg hole counts and egg numbers was in the unaltered leaders (.67). Needles obscured egg holes on these leaders and the resulting counts were low.

The highest variability in photo and visual counts was at the top 50mm of the leaders. Feeding is begun at the top of the leader near the new growth and the highest concentrations of eggs are found in this area.

Several seasonal changes interfered with the interpretation of the photographs. Large numbers of feeding punctures and large quantities of pitch on the top 50mm of the leader caused confusion in counting (fig. 1) as did developing larvae migrating down the leader. Additionally, landmarks changed as needle fascicles dropped off (fig. 3). Furthermore, the leaders had to be dissected within 2 weeks after cutting or saprophytic fungi obscured landmarks and egg holes.

Other factors that caused problems were

Figure 3.—Leader with needles removed (late in season).

wind, damage to leaders, and inadequate marking. Identifying marks should be made from the top of the leader to the first whorl at predetermined positions (N.E.S.W.). Marks at 50mm intervals should be made around the leader. Also, a support to stabilize the camera at a predetermined spot would enable the operator to shoot exactly corresponding pictures in successive weeks. These changes would improve the system, but the greatest success would still be achieved with leaders with a low needle density.

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SIMPLE MODELS FOR ESTIMATING LOCAL REMOVALS OF TIMBER IN THE NORTHEAST

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MANUSCRIPT RECEIVED FOR PUBLICATION 28 JUNE 1974

SIMPLE MODELS FOR ESTIMATING LOCAL REMOVALS OF TIMBER IN THE NORTHEAST

ABSTRACT

Provides a practical method of estimating subregional removals of timber and demonstrates its application to a typical problem. Stepwise multiple regression analysis is used to develop equations for estimating removals of softwood, hardwood, and all timber from selected characteristics of socioeconomic structure.

INTRODUCTION

Resource analysts at the Northeastern Forest Experiment Station are frequently asked (by resource planners, wood-industry representatives and others) to provide up-to-date estimates of local removals of timber in the Northeast. The Station's Forest Survey work unit helps meet this need by publishing annual reports on the production of pulpwood and data on all timber removals in conjunction with their periodic statewide forest inventories. But the timber cut for pulpwood is only a portion of the total removed, and timber-removal data collected at the time of state inventories are not current for many areas and are often not available for particular localities of interest. To solve this problem, we have developed models for estimating local timber removals. The models are easy to use and appear to work quite well for subregions of a million acres or more.

APPROACH

Underlying the development of the models was the premise that timber removal in any particular locale is related to, and can therefore be expressed as a function of, that locale's socioeconomic structure. Stepwise multiple regression analysis was used to develop equations for estimating timber removals as a function of selected characteristics of socioeconomic structure. Recent information compiled for 47 sample subregions in 12 northeastern states, (Connecticut, Delaware, Kentucky, Maine, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Vermont and West Virginia) provided data for the analysis.

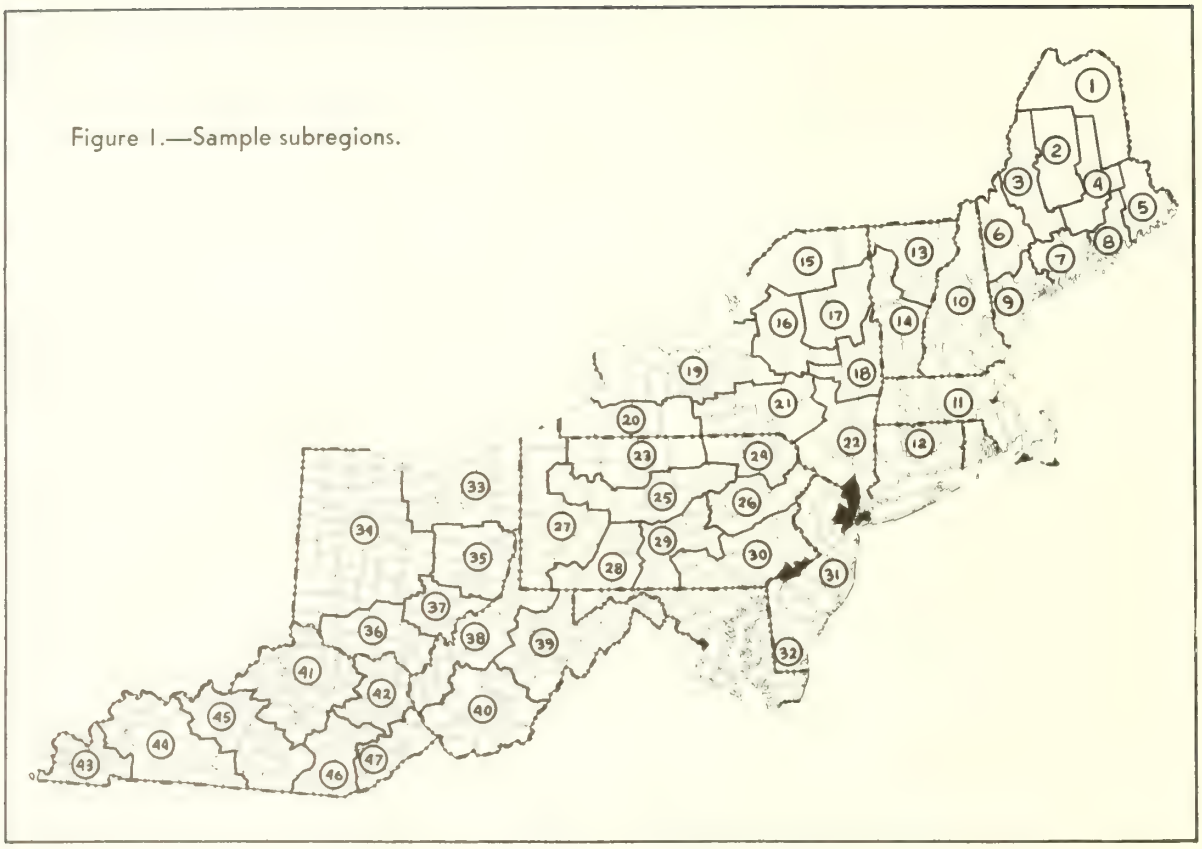

Figure 1.—Sample subregions.

Locations of the subregions are shown in figure 1.

The size of the sample subregions varies considerably, from 1 million to 12 million acres. We wanted to reduce the effect of subregion size as much as possible, so all variables whose values might be influenced by subregion size were expressed in units per acre of total land area.

Regressand Variables

Three regressand variables were selected for analysis:

Y_A = Current annual removal of *all timber* in cubic feet per acre of total land,

Y_S = Current annual removal of *softwood timber* (conifers: spruce, fir, pine, hemlock, etc.) in cubic feet per acre of total land, and

Y_H = Current annual removal of *hardwood timber* (broad-leaved trees: oak, yellow poplar, maple, ash, etc.) in cubic feet per acre of total land.

Estimates of current net annual removals of growing stock (for all purposes: wood products, land clearing, etc.) for each sample subregion were derived from records of the Northeastern Station's Forest Survey work unit.

Regressor Variables

Sixteen regressor variables were tested and the five marked by asterisks proved to be significant:

X_1 = Proportion of commercial forest land in public ownership

* X_2 = Softwood growing stock inventory in thousands of cubic feet per acre of total land

* X_3 = Hardwood growing stock inventory in thousands of cubic feet per acre of total land

* X_4 = Softwood sawtimber volume inventory in thousands of board feet per acre of total land

X_5 =Hardwood sawtimber volume inventory in thousands of board feet per acre of total land

X_6 =Softwoods as a proportion of total growing stock

X_7 =Commercial forest land as a proportion of total land

* X_8 =Number of lumber and wood-product firms (Standard Industrial Classification [SIC] 24) per thousand acres of total land

X_9 =Value added by all manufacture per thousand acres of total land

X_{10}=Furniture and lumber and wood-product employees (SIC 24 and 25) per thousand acres of total land

X_{11}=Furniture and lumber and wood-product employees (SIC 24 and 25) as a proportion of total employees

X_{12}=Total human population per acre of total land

X_{13}=Rural human population per acre of total land

X_{14}=Average level of education for males 25 years of age and more

* X_{15}=Per capita income in thousands of dollars

X_{16}=Rural road mileage per thousand acres of total land

There were two major reasons for selecting this particular set of variables. First, we feel they include the socioeconomic conditions that determine the amount of timber removed in any subregion of the Northeast. Second, data on each of these variables are readily available, for each county of the Northeast, from Census and Forest Survey publications.

Data for these variables provided the input for the regression equations. The coefficient for each successive regressor variable had to be significant at the .01 level to be included in an equation.

RESULTS

Stepwise multiple regression analyses gave us three simple equations for estimating current annual removals of timber (per acre of total land area) for subregions in the Northeast:

(1) All timber;

$$Y_A = 15.13 + 13.70X_2 + 116.49X_8 - 4.78X_{15} - 2.25X_4$$

$$R^2 = 0.84$$

(2) Softwood timber;

$$Y_S = -1.29 + 17.02X_2 + 28.99X_8$$

$$R^2 = 0.90$$

(3) Hardwood timber;

$$Y_H = 9.55 + 5.53X_3 + 63.01X_8 - 2.99X_{15} - 1.93X_4$$

$$R^2 = 0.69$$

Five of the original 16 regressor variables are included in these equations and their inclusion makes good sense. Variables X_2 (inventory of softwood growing stock volume), X_3 (inventory of hardwood growing stock volume), and X_4 (inventory of softwood sawtimber volume), are important indicators of the availability of local timber supplies. Variable X_8 (number of lumber and wood product firms) reflects local levels of market activity and timber demand. Variable X_{15} (per capita income) reflects affluence and the degree to which other land uses compete with timber production.

The position of the regressor variables in each equation indicates the relative importance of each variable as an estimator of timber removal. Variables on the left are more important than those on the right. For example, X_2 is much more important than X_4 in equation (1).

The coefficient of multiple determination (R^2) for each equation is at least 0.69. Thus the rather small number of regressor variables included in these equations explain a rather large share of the variation in timber removal for the sample subregions; the models fit the sample data quite well.

Table 1. Comparison of equation estimates with recorded estimates of current annual removals per acre of total land

Subregion	All timber removals				Softwood timber removals				Hardwood timber removals			
	Equation	Recorded	Difference	Relative error	Equation	Recorded	Difference	Relative error	Equation	Recorded	Difference	Relative error
	Cubic Feet			*Percent*	*Cubic Feet*			*Percent*	*Cubic Feet*			*Percent*
1	18.96	19.29	—0.33	1.7	15.16	16.27	—1.11	6.8	4.82	3.03	1.80	59.4
2	20.58	20.32	.26	1.3	16.84	14.76	2.08	14.1	5.76	5.56	.20	3.6
3	19.28	17.92	1.36	7.6	13.90	13.47	.43	3.2	6.56	4.45	2.11	47.4
4	21.76	26.59	—4.83	18.2	13.56	16.99	—3.43	20.2	8.20	9.60	—1.40	14.6
5	18.08	23.76	—5.68	23.9	12.05	16.16	—4.11	25.4	6.17	7.60	—1.43	18.8
6	23.22	25.21	—1.99	7.9	10.98	9.53	1.45	15.2	11.40	15.68	—4.28	27.3
7	16.47	20.02	—3.55	17.7	8.20	12.55	4.35	34.7	6.98	7.46	.48	6.4
8	16.73	11.12	5.61	50.4	11.20	8.67	2.53	29.2	5.50	2.44	3.06	[a]
9	23.54	17.52	6.02	34.4	10.78	11.53	— .75	6.5	10.46	5.99	4.47	74.6
10	12.49	11.14	1.35	12.1	9.78	5.55	4.23	76.2	5.22	5.59	— .37	6.6
11	9.66	7.11	2.55	35.9	5.37	2.87	2.50	87.1	5.17	4.24	.93	21.9
12	2.88	4.49	—1.61	35.9	2.06	.51	1.55	[a]	3.78	3.98	—.20	5.0
13	11.81	8.56	3.25	38.0	5.13	3.80	1.33	35.0	6.30	4.76	1.54	32.4
14	10.31	7.78	2.53	32.5	3.72	2.60	1.12	43.1	6.88	5.18	1.70	32.8
15	5.93	3.10	2.83	91.3	1.15	1.38	— .23	16.7	4.11	1.72	2.39	[a]
16	5.88	6.69	— .81	12.1	2.17	1.14	1.03	90.4	3.57	5.55	—1.98	35.7
17	8.01	8.68	— .67	7.7	3.13	2.15	.98	45.6	4.45	6.53	—2.08	31.9
18	3.25	4.31	—1.06	24.6	1.89	.80	1.09	[a]	2.06	3.52	—1.46	41.5
19	2.16	2.49	— .33	13.3	.08	.23	— .15	65.2	1.95	2.26	— .31	13.7
20	5.42	3.66	1.76	48.1	.57	.23	.34	[a]	4.66	3.44	1.22	35.5
21	4.10	3.67	.43	11.7	1.08	.69	.39	56.5	3.60	2.98	.62	20.8
22	1.56	1.29	.27	20.9	1.30	.16	1.14	[a]	1.99	1.13	.86	76.1
23	8.81	11.69	—2.88	24.6	1.26	.38	.88	[a]	11.52	11.31	.21	1.9
24	8.07	6.11	1.96	32.1	.93	.52	.41	78.8	6.96	5.59	1.37	24.5
25	9.72	12.65	—2.93	23.2	1.52	1.04	.48	46.2	9.42	11.61	—2.19	18.9
26	8.33	4.47	3.86	86.4	1.70	.52	1.18	[a]	7.10	3.95	3.15	79.7
27	5.88	4.70	1.18	25.1	.46	.21	.25	[a]	5.32	4.49	.83	18.5
28	10.79	14.74	—3.95	26.8	.85	.89	— .04	4.5	9.99	13.85	—3.86	27.9
29	13.75	11.39	2.36	20.7	1.03	1.42	— .39	27.5	11.68	9.96	1.72	17.3
30	3.48	3.52	— .04	1.1	.21	.20	.01	5.0	3.49	3.33	.16	4.8
31	4.35	2.43	1.92	79.0	1.42	.90	.52	57.8	3.24	1.53	1.71	[a]
32	5.41	10.18	—4.77	46.9	2.66	7.55	—4.89	64.8	3.48	2.62	.86	32.8
33	4.13	3.47	.66	19.0	— .02	.00	— .02	[a]	2.93	3.47	— .54	15.6
34	2.15	1.46	.69	47.3	— .68	.02	— .70	[a]	1.52	1.44	.08	5.6
35	6.66	7.51	— .85	11.3	— .21	.00	— .21	[a]	5.25	7.50	—2.25	30.0
36	7.61	9.21	—1.60	17.4	— .07	.28	— .35	[a]	6.23	8.93	—2.70	30.2
37	8.98	10.29	—1.31	12.7	.14	.22	— .08	36.4	7.36	10.07	—2.71	26.9
38	8.25	4.19	4.06	96.9	.23	.61	— .38	62.3	8.40	3.58	4.82	[a]
39	12.05	14.34	—2.29	16.0	1.42	1.64	— .22	13.4	12.32	12.71	— .39	3.1
40	9.83	13.32	—3.49	26.2	.57	.59	— .02	3.4	11.11	12.72	—1.61	12.7
41	— .43	1.13	—1.56	[a]	— .78	.11	— .89	[a]	— .75	1.03	—1.78	[a]
42	7.46	7.59	— .13	1.7	.61	.52	.09	17.3	6.08	7.07	— .99	14.0
43	3.83	3.59	.24	6.7	— .75	.07	— .82	[a]	3.73	3.52	.21	6.0
44	5.87	6.79	— .92	13.5	— .41	.02	— .43	[a]	4.37	6.77	—2.40	35.5
45	6.26	5.75	.51	8.9	— .19	.49	— .68	[a]	4.56	5.26	— .70	13.3
46	10.57	8.89	1.68	18.9	1.17	2.02	— .85	42.1	8.20	6.87	1.33	19.4
47	7.57	8.34	— .77	9.2	— .27	.76	—1.03	[a]	7.08	7.59	— .51	6.7

[a] Relative error is more than 100 percent or undefined.

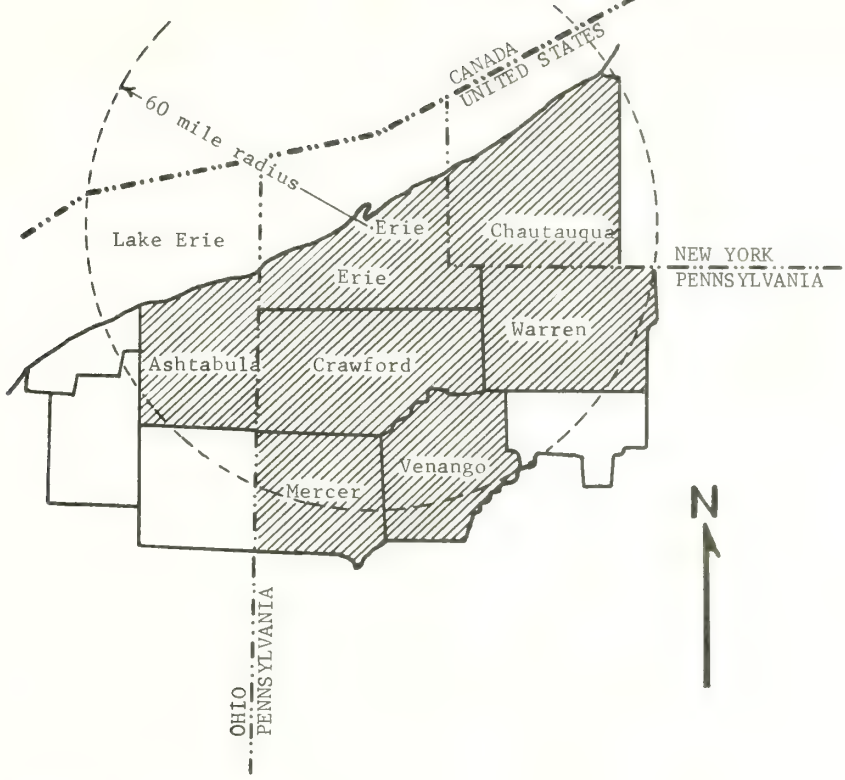

Figure 2.—Erie subregion.

A CHECK ON PERFORMANCE

Does it work? This is the real measure of any predictive model's worth. To examine performance, we applied the equations for estimating local timber removals to the 47 sample subregions used in this study. Removals estimated by the equations were compared with recorded estimates (table 1). Absolute differences between recorded and equation estimates range from 0.01 to 6.02 cubic feet. Relative errors in the equation estimates, i.e., the absolute differences between equation estimates and recorded estimates expressed as a percentage of recorded estimates, range from 1.1 to more than 100 percent. The relative error in equation estimates is less for sample subregions in which recorded amounts of timber removed are large. This implies that the models should perform best where the amount of timber removed is known to be large. In some cases, equation estimates of removal were negative, but this occurs only where recorded removals are zero or negligible.

The above comparisons are by no means an exhaustive test of model performance, but they do indicate the kind of results that users of the equations might expect.

AN APPLICATION

Now that we have the models how do we use them? Suppose we wanted to estimate the current annual removal of softwood, hardwood and all timber within a 60 mile radius of Erie, Pennsylvania (figure 2). This area is approximately the same as that included in Chautauqua county, New York; Ashtabula county, Ohio; and Erie, Crawford, Mercer, Warren, and Venango counties, Pennsylvania.

The first step is to determine values for the five regressor variables that are applicable to this problem. These values can be calculated very simply, using county data from the most recent Forest Survey and Census publications. For example, the value of X_2 (softwood growing stock inventory in

thousands of cubic feet per acre of total land) is determined as follows:

$$X_2 = \frac{\text{million cubic feet of softwood growing stock}}{\text{thousand acres of total land}}$$

For our seven-county subregion:

County	*Softwood growing stock (million cubic feet)*	*Total land area (thousand acres)*
Chautauqua, N. Y.	42.9[1]	691.6[1]
Ashtabula, Ohio	.6[2]	448.1[2]
Crawford, Pa.	17.3[3]	650.2[3]
Erie, Pa.	14.5[3]	519.7[3]
Mercer, Pa.	8.0[3]	435.8[3]
Venango, Pa.	39.5[3]	432.0[3]
Warren, Pa.	55.9[3]	582.4[3]
Subregion total	178.7	3,759.8

$$X_2 = \frac{178.7}{3,759.8} = 0.048$$

Similarly, values for the other four regressor variables are:

X_3 = Hardwood growing stock inventory in thousands of cubic feet per acre of total land[1, 2, 3]
= 0.488

X_4 = Softwood sawtimber volume inventory in thousands of board feet per acre of total land[1, 2, 3]
= 0.090

X_8 = Number of lumber and wood-product firms (SIC 24) per thousand acres of total land[1, 2, 3, 4]
= 0.052

X_{15} = Per capita income in thousands of dollars[5]
= 2.777

Now, we substitute these values into regression equations (2) and (3) to solve for Y_S and Y_H, respectively:

Y_S = The current annual removal of softwood timber
$= -1.29 + 17.02X_2 + 28.99X_8$
$= -1.29 + 17.02(0.048) + 28.99(0.052)$
= 1.04 cubic feet per acre of total land, and

Y_H = The current annual removal of hardwood timber
$= 9.55 + 5.53X_3 + 63.01X_8 - 2.99X_{15} - 1.93X_4$
$= 9.55 + 5.53(0.488) + 63.01(0.052) - 2.99(2.777) - 1.93(0.090)$
= 7.06 cubic feet per acre of total land.

Since Y_S and Y_H are per-acre values, we multiply them by the total acreage of land in the subregion to get estimates of the total annual removals of softwood and hardwood timber in the subregion. Thus: the estimated total annual removal of softwood timber = 1.04 (3,759,800) = 3.9 million cubic feet, and the estimated total annual removal of hardwood timber = 7.06 (3,759,800) = 26.5 million cubic feet.

These estimates of the softwood and hardwood timber removals can be added to get an estimate of the annual removal of all timber in the subregion: the estimated total annual removal of all timber = 3.9 + 26.5 = 30.4 million cubic feet.

An alternative method of estimating the annual removal of all timber is to solve regression equation (1) for Y_A and then multiply Y_A by the total acreage of land in the subregion:

Y_A = the current annual removal of all timber
$= 15.13 + 13.70X_2 + 116.49X_8 - 4.78X_{15} - 2.25X_4$
$= 15.13 + 13.70(0.048) + 116.49(0.052) - 4.78(2.777) - 2.25(0.090)$
= 8.38 cubic feet per acre of total land

[1] Source: Ferguson, Roland H. and Carl E. Mayer. 1970. THE TIMBER RESOURCES OF NEW YORK. USDA Forest Serv. Res. Pap. NE-20, 193 p.
[2] Source: Kingsley, Neal P. and Carl E. Mayer. 1970. THE TIMBER RESOURCES OF OHIO. USDA Forest Serv. Res. Pap. NE-19, 137 p.
[3] Source: Ferguson, Roland H. 1968. THE TIMBER RESOURCES OF PENNSYLVANIA. USDA Forest Serv. Res. Pap. NE-8, 147 p.
[4] Source: U.S. Bureau of the Census. 1971. CENSUS OF MANUFACTURES: 1967, Volume III: Area Statistics. U.S. Government Printing Office, Washington, D. C.
[5] Source: U.S. Bureau of the Census. 1972. CENSUS OF POPULATION: 1970: General Social and Economic Characteristics. PC(1)-C34 P. Y., PC(1)-C37 Ohio, and PC(1)-C40 Pa. U.S. Government Printing Office, Washington, D. C.

Then the estimated total annual removal of all timber in the subregion=8.38(3,759,800) =31.5 million cubic feet. The difference between the two alternative estimates of the total annual removal of all timber=31.5–30.4 =1.1 million cubic feet. In this case the difference is less than 4 percent of either estimate. Results will vary from case to case.

SUMMARY

Resource analysts have long needed a practical method of estimating current removals of timber for local areas in the Northeast. In response to this need, we have developed regression equations for estimating subregional removals of softwood, hardwood, and all timber as a function of selected characteristics of socioeconomic structure. Five key regressor variables are included in the equations. These variables reflect conditions of timber availability, market activity and demand, and land-use competition that determine the amount of local timber removed.

The regression models can be used to estimate timber removals for any subregion of the Northeast. But they are likely to perform best for areas of a million acres or more where the quantity of timber removed is known to be large.

Larsen, David N., and David A. Gansner
1975. **Simple models for estimating local removals of timber in the Northeast.** NE. Forest Exp. Stn., Upper Darby, Pa.
7 p., illus. (USDA Forest Serv. Res. Pap. NE-319)

Provides a practical method of estimating subregional removals of timber and demonstrates its application to a typical problem. Stepwise multiple regression analysis is used to develop equations for estimating removals of softwood, hardwood, and all timber from selected characteristics of socioeconomic structure.

905.2(74)--015.5

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A Multivariate Model and Statistical Method for Validating Tree Grade Lumber Yield Equations

by Donald W. Seegrist

USDA FOREST SERVICE RESEARCH PAPER NE-320
1975

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MANUSCRIPT RECEIVED FOR PUBLICATION 21 JANUARY 1975

A Multivariate Model and Statistical Method for Validating Tree Grade Lumber Yield Equations

ABSTRACT

Lumber yields within lumber grades can be described by a multivariate linear model. A method for validating lumber yield prediction equations when there are several tree grades is presented. The method is based on multivariate simultaneous test procedures.

Tree grading systems are designed to classify trees by value. Hardwood sawtimber grading systems have rules for determining tree grade and a set of equations or tables for predicting lumber yield by lumber grades within each tree grade.

When a grading system is developed, a sample of trees, the "index sample", is selected and a number of external characteristics are measured on each tree. Then the key variables —those that separate the trees into value classes—are determined. The grading rules are based on these key variables. In addition, a set of regression equations for predicting lumber yields by lumber grade is developed. The yields are usually functions of tree diameter and length.

The next step is to validate the regression equations. This is usually done by comparing the lumber yields predicted from the regression equations with the actual yields obtained from the second, or "validation" sample of trees. The validation should be done by comparing the lumber yield equations in the validation sample and the index sample.

The main purpose of this paper is to present this statistical method of validating the regression equations. A second purpose is to familiarize foresters with multivariate general linear models and multivariate analysis of variance (MANOVA). As an example I have used white oak graded with the Interim Hardwood Tree Grades for factory lumber.

White oak has eight lumber grades and three tree grades. Therefore there are 24 regression equations for predicting lumber volume. The independent variables are

$x_1 = 1$

$x_2 =$ square of the tree diameter (d^2)

$x_3 =$ tree height (h)

and $x_4 = d^2h$.

The variable $x_1 = 1$ allows for intercepts in the regression model.

The dependent variables are

$y_1 =$ volume of FAS lumber

$y_2 =$ volume of FASF lumber

$y_3 =$ volume of Select lumber

$y_4 =$ volume of 1C lumber

$y_5 =$ volume of 2C lumber

$y_6 =$ volume of SW lumber

$y_7 =$ volume of 3A lumber

and $y_8 =$ volume of 3B lumber.

The measurements on the k^{th} sample tree in the j^{th} tree grade in the i^{th} sample can be written in vector notation as

$$[x_{ijk}, y_{ijk}] = [1\ x_{2ijk}\ x_{3ijk}\ x_{4ijk}\ y_{1ijk} \ldots y_{8jjk}].$$

THE MULTIVARIATE REGRESSION MODEL

The usual procedure for developing the lumber volume prediction equations is to develop, one at a time, univariate multiple regression equations for lumber grade in each tree grade. However, the lumber volumes are known to be highly correlated and the correlation among lumber yields should be part of the statistical model. A multivariate multiple regression model can describe the vectors of lumber volumes. Morrison (*1967*). has given an excellent discussion of the multivariate general linear model and multivariate analysis of variance (MANOVA).

The multivariate regression model for the vector of lumber yields for k^{th} sample tree in the j^{th} tree grade in the i^{th} sample is

$$y_{ijk} = x_{ijk}\,\beta_{ij} + \varepsilon_{ijk}.$$

The model describing the set of measurements on the n_{ij} trees in the j^{th} tree grade of the i^{th} sample can be succinctly written in matrix notation as

$$\mathbf{Y}_{ij} = \mathbf{X}_{ij}\,\beta_{ij} + \varepsilon_{ij}$$

where $\mathbf{Y}_{ij}$ is a $n_{ij} \times 8$ matrix of dependent variables, $\mathbf{X}_{ij}$ is a $n_{ij} \times 4$ "design" matrix. β_{ij} is a 4×8 matrix of regression coefficients, and ϵ_{ij} is a $n_{ij} \times 8$ matrix of errors.

A model that combines the observations for the three tree grades and two samples is

$$\begin{bmatrix} \mathbf{Y}_{11} \\ \mathbf{Y}_{12} \\ \mathbf{Y}_{13} \\ \mathbf{Y}_{21} \\ \mathbf{Y}_{22} \\ \mathbf{Y}_{23} \end{bmatrix} = \begin{bmatrix} \mathbf{X}_{11} & & & & & \\ & \mathbf{X}_{12} & & & 0 & \\ & & \mathbf{X}_{13} & & & \\ & & & \mathbf{X}_{21} & & \\ & 0 & & & \mathbf{X}_{22} & \\ & & & & & \mathbf{X}_{23} \end{bmatrix} \begin{bmatrix} \beta_{11} \\ \beta_{12} \\ \beta_{13} \\ \beta_{21} \\ \beta_{22} \\ \beta_{23} \end{bmatrix} + \begin{bmatrix} \epsilon_{11} \\ \epsilon_{12} \\ \epsilon_{13} \\ \epsilon_{21} \\ \epsilon_{22} \\ \epsilon_{23} \end{bmatrix}$$

An example of the data needed for the model is given in figure 1. Symbolically the combined model can be written as

$$\begin{bmatrix} \mathbf{Y}_1 \\ \mathbf{Y}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 & 0 \\ 0 & \mathbf{X}_2 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix}.$$

It is assumed that

$$\text{and } E[\varepsilon_{ijk}] = 0 \text{ for all ijk}$$
$$E[\varepsilon'_{ijk}\,\varepsilon_{ijk}] = \Sigma \text{ for ijk} = \text{ijk}',$$
$$= 0 \text{ otherwise.}$$

Further, it is assumed the vectors of errors have a multivariate normal distribution.

MULTIVARIATE LEAST SQUARES ESTIMATORS AND TESTS

Using multivariate least squares procedures, the multivariate normal equations are

$$\begin{bmatrix} \mathbf{X}_1'\mathbf{X}_1 & 0 \\ 0 & \mathbf{X}_2'\mathbf{X}_2 \end{bmatrix} \begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1'\mathbf{Y}_1 \\ \mathbf{X}_2'\mathbf{Y}_2 \end{bmatrix}.$$

The solution of the normal equation is

$$\begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{bmatrix} = \begin{bmatrix} [\mathbf{X}_1'\mathbf{X}_1]^{-1} & \mathbf{X}_1'\mathbf{Y}_1 \\ [\mathbf{X}_2'\mathbf{X}_2]^{-1} & \mathbf{X}_2'\mathbf{Y}_2 \end{bmatrix}$$

The matrix of residuals is

$$\mathbf{E} = [\mathbf{Y}_1'\mathbf{Y}_1 - \mathbf{Y}_1'\mathbf{X}_1\mathbf{b}_1] + [\mathbf{Y}_2\mathbf{Y}_2 - \mathbf{Y}_2'\mathbf{X}_2\mathbf{b}_2].$$

With multivariate analysis of variance (MANOVA) one can test hypotheses of the form

$$\mathbf{A}\beta\mathbf{C}' = \mathbf{D}.$$

The hypothesis sums of products matrix is

$$\mathbf{H} = [\mathbf{AbC}' - \mathbf{D}]'\,[\mathbf{A}[\mathbf{X}'\mathbf{X}]^{-1}\,\mathbf{A}']^{-1}\,[\mathbf{AbC}' - \mathbf{D}].$$

The error sums of products matrix is

$$\mathbf{S} = \mathbf{CEC}'.$$

Several test statistics are available for testing multivariate hypotheses.

HYPOTHESIS TESTING OF THE TREE GRADE LUMBER VOLUME REGRESSION EQUATIONS

There are many relevant hypotheses about the tree-grade regression equations for the index and validation samples. These hypotheses can all be expressed as linear combinations of the parameters of an overall hypothesis. The overall hypothesis is that the sets of regression equations for the two samples are the same. If the overall hypothesis is accepted, differences between the two sets of regression

equations are attributed to chance and the equations are valid.

If the overall hypothesis is rejected, further questions arise. Are the two sets of regression equations different for all tree grades or only for some tree grades? What tree-grade regressions are different for which lumber grades? Also, one might test whether the predicted lumber volumes are the same for an average size tree in the two samples. Are the predicted volumes of average size trees the same for all lumber grades or just some lumber grades? Hypotheses concerning the total lumber volume and total value are also relevant. If some of these hypotheses (for example, the equality of lumber yield predictions for average size trees) are accepted, the equations might be considered valid.

The overall and the relevant hypotheses for white oak are presented below as an example.

The Overall Hypothesis

Formally, the overall hypothesis that the regression equations for the two samples are the same for the three tree grades and eight lumber grades is

$$\begin{array}{ll} \beta_{11} = \beta_{21} & \beta_{11} - \beta_{21} = 0 \\ \beta_{12} = \beta_{22} \quad \text{or} & \beta_{12} - \beta_{22} = 0 \\ \beta_{13} = \beta_{23} & \beta_{13} - \beta_{23} = 0. \end{array}$$

In MANOVA notation, the overall hypothesis is

$$\Psi_o = [\mathbf{I}, -\mathbf{I}]\ \beta\ \mathbf{I} = 0$$

$$\text{where } \mathbf{I} = \begin{bmatrix} 1 & 0 & & 0 \\ 0 & 1 & & 0 \\ & & \cdots & \\ 0 & 0 & & 1 \end{bmatrix}, \beta = \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix},$$

$$\text{and } \mathbf{0} = \begin{bmatrix} 0 & 0 & & 0 \\ 0 & 0 & & 0 \\ & & \cdots & \\ 0 & 0 & & 0 \end{bmatrix}.$$

The Matrix **I** is called an identity matrix and **0** is called a null matrix. Note that $3 \times 8 = 24$ regressions for each sample are being compared. However, the overall hypothesis has 96 parameters since each regression equation has four coefficients.

Component Hypotheses

The overall hypothesis can be resolved into component hypotheses. A component hypothesis is the equality of the two sample regressions for one tree grade and one lumber grade. The component hypotheses depend on certain rows of the prematrix [**I**, -**I**] and one of the columns of the postmatrix **I**. For example, the hypothesis that the regression equations for tree grade 2 and select lumber are the same for the two samples is

$$\Psi_1 = [\mathbf{0}\ \mathbf{I}\ \mathbf{0}\ \mathbf{0}\ \text{-}\mathbf{I}\ \mathbf{0}]\ \beta \quad [0\ 0\ 1\ 0\ 0\ 0\ 0\ 0]' = 0$$

where **0** and **I** are 4×4 matrixes. Altogether there are 24 possible component hypotheses for the white oak grading system. The dimensions of each component hypothesis are 4×1.

Predicted Lumber Volumes Conditional on Average Size Trees

The overall hypothesis implies all possible linear combinations of the overall hypothesis. One relevant linear combination is the predicted lumber volume for the average size tree. The predictions are made from the population mean vector. For example, the population mean vector for the j^{th} tree grade is

$$\mu_j = [1, \mu_{2j}, \mu_{3j}, \mu_{4j}]$$

where μ_{2j} = population mean diameter squared,
μ_{3j} = population mean height,
and μ_{4j} = population mean diameter squared $\times$ height.

One hypothesis of interest is the equality of predicted lumber volume for the two samples conditional on the mean vector. The hypothesis is

$$\begin{aligned} \mu_1\ \beta_{11} &= \mu_1\ \beta_{21} \\ \mu_2\ \beta_{12} &= \mu_2\ \beta_{22} \\ \mu_3\ \beta_{13} &= \mu_3\ \beta_{23}\ . \end{aligned}$$

In MANOVA notation, the hypothesis is

$$\Psi_{21} = \begin{bmatrix} \mu_1 & 0 & 0 & -\mu_1 & 0 & 0 \\ 0 & \mu_2 & 0 & 0 & -\mu_2 & 0 \\ 0 & 0 & \mu_3 & 0 & 0 & -\mu_3 \end{bmatrix} \beta\ \mathbf{I} = 0.$$

Denoting the prefactor matrix in Ψ_{21} as $[\mu,-\mu]$, the hypothesis can be written as $[\mu,-\mu]\ \beta\ \mathbf{I} = \mathbf{0}$. Factoring μ out of the prefactor matrix gives $\mu\ [\mathbf{I},-\mathbf{I}]\ \beta\ \mathbf{I} = \mathbf{0}$, which shows that Ψ_{21} is a linear combination of the overall hypothesis. The dimensions of Ψ_{21} are 3×8 compared to 12×8 for Ψ_o.

One of the peculiarities of sawing logs is that the sawyer has considerable leeway in the way a log is cut. Therefore the proportions of lumber grades may vary. Consequently the lumber volume equations and predictions may differ from one sample to another because there is a difference in the way the logs were sawn. Although the lumber volume predictions may differ, certain combinations of lumber volume predictions should be the same.

White oak lumber grades can be divided into three groups, with the grades in each group having more or less the same value per board foot. The groups are (1) select lumber and better, (2) number one common (1C), and (3) 2C and poorer. Suppose one wants to test whether the predicted volumes of the most valuable (select and better), intermediate (1C), and least valuable (2C and poorer) lumber grades are the same. In MANOVA notation, the hypothesis is

$$\Psi_{22} = [\mu,-\mu]\ \beta \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix}' = 0.$$

One is also interested in hypotheses involving the total lumber volume. For example, the hypothesis that the predicted total lumber volumes for the two samples are the same is

$$\Psi_{23} = [\mu,-\mu]\ \beta\ \mathbf{1}' = 0$$

where $\mathbf{1}' = [1\ 1\ \ldots\ 1]'$. The vector $\mathbf{1}'$ is called a summation vector. The dimensions of Ψ_{21} are 3×1.

Predicted Lumber Volume Conditional on Expected Tree Grade Proportions

Other relevant hypotheses involve the weighted average of the tree grades. The weights should be the true proportion of trees in each tree grade. One hypothesis is that there is no difference between the average lumber volume predictions for the two samples for each lumber grade. In MANOVA notation, the hypothesis is

$$\Psi_{31} = [\Pi_1\mu_1,\ \Pi_2\mu_2,\ \Pi_3\mu_3,-\Pi_1\mu_1,-\Pi_2\mu_2,-\Pi_3\mu_3]\beta\ \mathbf{I} = \mathbf{0}$$

where Π_1, Π_2, and Π_3 are the true proportion in tree grades 1, 2, and 3 respectively. Let the vector of proportions be $\Pi = [\Pi_1,\Pi_2,\Pi_3]$. The hypothesis Ψ_{31} can be written as $[\Pi\mu,-\Pi\mu]\ \beta\ \mathbf{I} = \mathbf{0}$.

Hypotheses Ψ_{31} tests the equality of the predicted lumber volumes for a stand of expected tree grade composition with average size white oaks. The hypothesis Ψ_{31} is also a linear combination of Ψ_o. The dimensions of Ψ_{31} are 1×8.

If we want to test the hypothesis that there is no difference in the total lumber yield, the postfactor is the summation matrix. The hypothesis is

$\Psi_{32} = [\Pi\mu,-\Pi\mu]\ \beta\ \mathbf{1}' = 0$. The function Ψ_{32} is a scalar, that is, the dimensions of Ψ_{32} are 1×1. The hypothesis consists of one parametric function.

Predicted Lumber Values

Another set of relevant hypotheses involves the value of the lumber. Let $\mathbf{v} = [v_1\ v_2\ \ldots\ v_8]$ be the vector of average values for the eight white oak lumber grades. The hypothesis that the predicted total values of lumber for the two samples are the same for the three tree grades simultaneously is

$$\Psi_{41} = [\mu,-\mu]\ \beta\ \mathbf{v}' = \mathbf{0}.$$

This hypothesis tests the equality of the total predicted value for average size trees, for the three tree grades simultaneously.

The average size trees can also be weighted by their relative frequencies. The resulting hypothesis is a scalar hypothesis which tests the equality of the predicted total value of the lumber. The hypothesis is

$$\Psi_{42} = [\Pi\mu,-\Pi\mu]\ \beta\ \mathbf{v}' = 0.$$

Weighting the tree grades by their relative frequencies gives more weight to the lower grades, which are more common, while weight-

ing the lumber grades by their mean values gives more weight to the better tree grades, which are more valuable.

TESTING PROCEDURE

The overall hypothesis, that the 24 regression equations for the index sample are the same as those for the validation sample, is a matrix of 96 parameters. If there is a significant difference between the sets of equations, the overall hypothesis, as a whole, does not hold. Simultaneous test procedures (STP) will show which sets of parameters cause the hypothesis to be rejected (*Gabriel 1968*).

A simultaneous test procedure rejects all hypotheses for which a particular statistic exceeds a single common critical value and accepts all others. A 5 percent level of an STP means that the probability of rejecting one or more true hypotheses out of all those tested is no more than 5 percent, whether the overall hypothesis or only some of its components are true. The significance level is said to be experimentwise rather than testwise.

Gabriel (*1956*) suggests several multivariate test statistics that can be used in a simultaneous test procedure.

$$\theta = C_1 [S^{-1}H] / [1 + C_1 [S^{-1}H]]$$
$$T^2 = n_e \text{ tr } [S^{-1}H]$$
$$U = |S| / |S+H|$$
and $$V = \text{tr } [[S+H]^{-1} H].$$

The notation $C_1[.]$ stands for the maximum characteristic root, tr [.] stands for the trace of a matrix, and |.| stands for the determinant of a matrix.

For the white oak example, the maximum root statistic θ is used as an STP. The critical value, for a 5 percent level STP, is the upper 5 percent point of the null distribution of θ for the overall hypothesis. There are $p_o = 8$ lumber grades, $r_o = 3 \times 4 = 12$ parameters, and $n_e = 316$ degrees of freedom. The parameters of the null distribution of θ are $s = \min (p_o, r_o) = 8$, $m = 1/2 (|r_o - p_o| - 1) = 3/2$, and $n = 1/2 (n_e - p_o - 1) = 153.5$. The critical value of θ at the .05 level is 0.13329 (see *Pallai 1965*). The maximum root STP compares the calculated value of θ for any hypothesis, including the overall hypothesis, to the value 0.13329. Any hypothesis is rejected if the calculated θ exceeds 0.13329.

WHITE OAK TEST STATISTICS

Data on a sample of white oak trees were obtained from Leland Hanks of the Northeastern Forest Experiment Station. His findings will be reported elsewhere.

The number of sample trees in the two samples was

	Tree Grade			
Sample	*I*	*II*	*III*	*Total*
Index	108	122	75	305
Validation	8	13	14	35.

The validation sample is considered to be a random sample from the white oak population of interest. The sample mean vector and proportions are used to estimate the population mean vector and proportions. For example, the vector for the second sample for the j^{th} tree grade is

$$\bar{x}_{2j} = [1 , \bar{d}^2_{2j} , \bar{h}_{2j} , \overline{d^2 h}_{2j}]$$

where $\bar{d}^2_{2j} = \sum_{k=1}^{n_{2j}} d_{2jk}{}^2 / n_{2j}$

$$\bar{h}_{2j} = \sum_{k=1}^{n_{2j}} h_{2jk} / n_{2j}$$

and $$\overline{d^2 h}_{2j} = \sum_{k=1}^{n_{2j}} d^2 h_{2jk} / n_{2j}.$$

The mean vectors are

$$x_{21} = [1.0 \quad 370.6 \quad 38.7 \quad 14435.8]$$
$$x_{22} = [1.0 \quad 317.8 \quad 36.8 \quad 11821.2]$$
$$x_{23} = [1.0 \quad 289.7 \quad 36.9 \quad 11215.8].$$

The proportion of logs in the j^{th} tree grade in the validation sample is $p_j = n_{2j} / (n_{21} + n_{22} + n_{23})$.

The proportions of trees in the validation sample are $p_1 = .2286$, $p_2 = .3714$, and $p_3 = .4000$. Multiplying the mean vectors by the proportions gives

$$p_1 x_{21} = [.2286 \quad 84.7 \quad 8.8 \quad 3298.6]$$
$$p_2 x_{22} = [.3714 \quad 118.0 \quad 13.7 \quad 4390.4]$$
$$p_3 x_{23} = [.4000 \quad 115.9 \quad 14.8 \quad 4486.3].$$

The average prices for the white oak lumber are

Grade	*$/fbm*
FAS	.24511
FASIF	.23439
SELECT	.22169
1C	.17004
2C	.09961
SW	.09808
3A	.08867
3B	.06094

The vector of average prices is

$$v = [0.24511 \ldots 0.06094].$$

To test the hypotheses involving the mean vector one can use $\bar{x}_{21}$, $\bar{x}_{22}$, and $\bar{x}_{23}$ in place of μ_1, μ_2, and μ_3. Likewise one can use p_1, p_2, and p_3 in place of Π_1, Π_2, and Π_3. The vector $\Pi\mu$ is replaced by $[p_1\bar{x}_{21}, p_2\bar{x}_{22}, p_3\bar{x}_{23}]$.

Estimates of the regression coefficients and test statistics were computed with a modified version of the Multivariate General Linear Hypothesis Program (BMDX63) (*Dixon 1969*). A partial listing of the data and a printout of the computer output follow.

The computed value of the test statistic for the overall hypothesis is 0.10933, which is less than the critical value. Therefore, in this example, the overall hypothesis is accepted. The differences between the two sets of regression equations may be due to chance. Since the overall hypothesis is accepted, there is no need to test component hypotheses and other relevant linear combinations. The sets of regression equations based on the index sample are accepted.

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APPENDIX

The first page presents a partial listing of the white oak data. The data is in the form for the multivariate regression model. Each line contains data from one tree. The first 12 columns contain values of the four independent variables for each of the three tree grades in the index sample. The next 12 columns contain the same data for the validation sample. The last eight columns are values of the lumber yields.

The second page shows the regression coefficients and the residual matrix. This is followed by the hypothesis matrices and test statistics for each of the hypotheses discussed in the paper.

PARTIAL LISTING OF WHITE OAK TEST DATA

| | | |

BMDX63 - MULTIVARIATE GENERAL LINEAR HYPOTHESIS - REVISED MAY 10, 1968
HEALTH SCIENCES COMPUTING FACILITY, UCLA

OAK LEE HANKS DATA

NO. OF INDEPENDENT VARIABLES 24
NO. OF DEPENDENT VARIABLES 8
NO. OF OBSERVATIONS 340
NO. OF HYPOTHESES 9

REGRESSION COEFFICIENTS $B=(X'X)^{-1}X'Y$

1	-49.74578	38.61154	-22.20332	121.45298	-55.98549	12.07271	-45.71794	12.14341
2	0.21179	-0.00547	0.04969	-0.21281	0.09960	-0.08540	0.11320	-0.00190
3	0.38402	-1.31154	0.45801	-4.99858	1.29745	-0.37565	1.83333	0.26926
4	-0.00124	0.00257	-0.00048	0.01455	0.00283	0.00347	-0.00126	0.00073
5	-3.97260	-27.02114	5.66302	-108.02191	-18.51471	-24.13804	16.63381	30.66055
6	0.04218	0.12346	-0.00714	0.38703	0.04071	0.01612	-0.04201	-0.06572
7	-0.06012	0.56331	-0.10537	1.25788	-0.04723	0.86514	0.04420	0.07194
8	0.00010	-0.00177	0.00035	-0.00081	0.00600	0.00105	0.00328	0.00185
9	1.76068	-4.38396	-2.56438	81.81661	7.69042	-22.39903	-20.19143	-17.86638
10	0.00727	0.04861	0.00444	-0.10565	0.01809	0.04556	0.08689	0.03783
11	-0.18492	-0.02890	0.13489	-3.97969	-0.85289	0.57048	0.89217	1.71251
12	0.00054	-0.00047	-0.00018	0.01117	0.00736	0.00134	0.00042	-0.00055
13	124.60510	-72.15117	37.22445	20.35130	-79.85826	102.19312	-63.53607	103.85335
14	-0.33902	0.23511	-0.13842	0.18170	0.06930	-0.21169	0.05584	-0.20968
15	-5.48285	1.99242	-1.90425	-2.13923	1.89379	-1.29430	2.17140	-0.56725
16	0.01663	-0.00600	0.00679	0.00395	0.00323	0.00286	0.00124	0.00280
17	-3.36754	32.11777	-3.60426	-8.82129	10.08515	-42.13702	-107.03810	205.72110
18	0.12444	-0.10843	0.04530	0.16771	0.09155	0.19896	0.29871	-0.69673
19	-1.02305	-0.80666	0.02598	-2.04251	-0.07262	0.94057	3.67817	-5.74273
20	0.00146	0.00323	-0.00058	0.00629	0.00186	-0.00365	-0.00622	0.02278
21	-9.73343	23.14028	-9.73343	68.76658	-61.25674	51.28313	-59.09157	9.73165
22	0.05620	-0.06781	0.05620	-0.00915	0.37403	-0.14646	0.40238	-0.31801
23	0.16855	-0.80949	0.16855	-3.00000	0.75424	-1.58855	1.48929	1.49619
24	-0.00108	0.00259	-0.00108	0.00590	-0.00194	0.00580	-0.00614	0.00849

RESIDUAL SUM OF PRODUCT MATRIX $E=Y'Y-Y'XB$

1	1549.08744	269.59309	62.73361	-383.67557	-626.05759	-1092.12031	-65.02085	-324.88452
2	269.59309	1190.56573	-29.86247	180.38170	-377.88049	-449.30010	158.50438	-193.41953
3	62.73361	-29.86247	238.80577	-13.42369	34.24962	3.27135	-145.39851	-116.03618
4	-383.67557	180.38170	-13.42369	6162.23977	842.40438	-398.33432	-504.28024	-1613.92685
5	-626.05759	-377.88049	34.24962	842.40438	5171.43888	-195.91976	-40.43333	-1471.34936
6	-1092.12031	-449.30010	3.27135	-398.33432	-195.91976	5167.14675	-575.64761	550.25962
7	-65.02085	158.50438	-145.39851	-504.28024	-40.43333	-575.64761	2243.37720	43.67915
8	-324.88452	-193.41953	-116.03618	-1613.92685	-1471.34936	550.25962	43.67915	3005.00838

OUTPUT FOR HYPOTHESIS NUMBER 1 (I,-I)BI OVERALL

A MATRIX

1	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000

C MATRIX

1	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000

D MATRIX

1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CONTRAST ABC'-D

1	-174.3509	110.7627	-59.4278	101.1017	23.8728	-90.1104	17.8181	-91.7099
2	0.5508	-0.2406	0.1881	-0.3945	0.0313	0.1263	0.0574	0.2078
3	5.8669	-3.3040	2.3623	-2.8594	-0.5963	0.9186	-0.3381	0.8365
4	-0.0179	0.0086	-0.0073	0.0106	-0.0004	0.0006	-0.0025	-0.0021
5	-0.6051	-59.1389	9.2673	-99.2006	-28.5999	17.9990	123.6719	-175.0605
6	-0.0823	0.2319	-0.0524	0.2193	-0.0508	-0.1828	-0.3407	0.6310
7	0.9629	1.3700	-0.1313	3.3004	0.0254	-0.0754	-3.6340	5.8147
8	-0.0014	-0.0050	0.0009	-0.0071	0.0041	0.0047	0.0095	-0.0209
9	11.4941	-27.5242	7.1691	13.0500	68.9472	-73.6822	38.9001	-27.5980
10	-0.0489	0.1164	-0.0518	-0.0965	-0.3559	0.1920	-0.3155	0.3558
11	-0.3535	0.7806	-0.0337	-0.9797	-1.6071	2.1590	-0.5971	0.2163
12	0.0016	-0.0031	0.0009	0.0053	0.0093	-0.0045	0.0066	-0.0090

CEC'

1	1649.0874	269.5931	62.7336	-383.6756	-626.0576	-1082.1203	-65.0209	-324.8845
2	269.5931	1190.5657	-29.8625	180.3817	-377.8805	-449.3001	158.5044	-193.4195
3	62.7336	-29.8625	238.8058	-13.4237	34.2496	3.2713	-145.3985	-116.0362
4	-383.6756	180.3817	-13.4237	6162.2398	842.4044	-398.3343	-504.2802	-1613.9269
5	-626.0576	-377.8805	34.2496	842.4044	5171.4389	-195.9198	-40.4333	-1471.3494
6	-1082.1203	-449.3001	3.2713	-398.3343	-195.9198	5167.1467	-575.6476	550.2596
7	-65.0209	158.5044	-145.3985	-504.2802	-40.4333	-575.6476	2243.3772	43.6792
8	-324.8845	-193.4195	-116.0362	-1613.9269	-1471.3494	550.2596	43.6792	3005.0084

HYPOTHESIS SUM OF PRODUCT MATRIX, H=(ABC'-D)'(A(X'X)$^{-1}$A')$^{-1}$(ABC'-D)

1	54.8037	-30.0177	19.6861	-2.2543	-3.7798	-19.0558	19.3578	-5.2211
2	-30.0177	40.9538	-14.8201	-0.3642	9.5295	16.2217	-28.5347	-4.9734
3	19.6861	-14.8201	10.3884	-3.1874	2.2620	-9.6905	12.4153	-10.0533
4	-2.2543	-0.3642	-3.1874	73.8244	48.4253	51.0869	-5.7491	-62.2763
5	-3.7798	9.5295	2.2620	48.4253	82.5368	40.8542	10.5372	-106.0128
6	-19.0558	16.2217	-9.6905	51.0869	40.8542	76.8403	-22.7490	-51.2851
7	19.3578	-28.5347	12.4153	-5.7491	10.5372	-22.7490	51.2437	-29.3219
8	-6.2211	-4.9734	-10.0533	-62.2763	-106.0128	-51.2851	-29.3219	178.5239

DETERMINANT(CEC') = .216343852559630+27 DETERMINANT(CEC'+H) = .276101180231000+27
U-STATISTIC = .783567250 DEGREES OF FREEDOM 8 12 316
F-STATISTIC = .803372383 DEGREES OF FREEDOM 96 2092.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .12274766
HECK'S THETA WITH PARAMETERS S,M,N 8 1.5 153.5 .10932791

OUTPUT FOR HYPOTHESIS NUMBER 2 (0,I,0,0,-I,0)B(00100000)' COMPONENT 2,3

A MATRIX

1	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	0.0	0.0	0.0	0.0

C MATRIX

1	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0

D MATRIX

1	0.0
2	0.0
3	0.0
4	0.0

CONTRAST ABC'-D

1	-59.1389
2	0.2319
3	1.3700
4	-0.0050

CEC'

1	1190.5657

$$\text{HYPOTHESIS SUM OF PRODUCT MATRIX, } H=(ABC'-D)'(A(X'X)^{-1}A')^{-1}(ABC'-D)$$

1	9.6245

DETERMINANT(CEC') = 1190.5657320470 DETERMINANT(CEC'+H) = 1200.1902413705
U-STATISTIC = .991980791 DEGREES OF FREEDOM 1 4 316
F-STATISTIC = .638638735 DEGREES OF FREEDOM 4 316.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .80839798D-02
HECK'S THETA WITH PARAMETERS S,M,N 1 1.0 157.0 .80191531D-02

OUTPUT FOR HYPOTHESIS NUMBER 3 (X,-X)BI PREDICTED VOLUMES

A MATRIX

1	1.0000	370.6000	38.7000	14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-1.0000	-370.6000	-38.7000	-14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	1.0000	317.8000	36.8000	11821.2000	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	-1.0000	-317.8000	-36.8000	-11821.2000	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	286.7000	36.9000	11215.8000
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	-286.7000	-36.9000	-11215.8000

C MATRIX

1	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000

D MATRIX

1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CONTRAST ABC'-D

1	-1.2561	17.4285	-3.2203	-2.6593	6.5268	1.0317	-10.1939	-12.2693
2	-7.4015	5.9361	-1.3219	8.0379	5.1968	12.6175	-5.9701	-7.8766
3	2.6024	0.2888	1.2420	8.3686	11.9328	11.0054	0.0041	-18.9316

CEC'

1	1649.0874	269.5931	62.7336	-383.6756	-626.0576	-1082.1203	-65.0209	-324.8845
2	269.5931	1190.5657	-29.8625	180.3817	-377.8805	-449.3001	158.5044	-193.4195
3	62.7336	-29.8625	238.8058	-13.4237	34.2496	3.2713	-145.3985	-116.0362
4	-383.6756	180.3817	-13.4237	6162.2398	842.4044	-398.3343	-504.2802	-1613.9269
5	-626.0576	-377.8805	34.2496	842.4044	5171.4389	-195.9198	-40.4333	-1471.3494
6	-1082.1203	-449.3001	3.2713	-398.3343	-195.9193	5167.1467	-575.6476	550.2596
7	-65.0209	158.5044	-145.3985	-504.2802	-40.4333	-575.6476	2243.3772	43.6792
8	-324.8845	-193.4195	-116.0362	-1613.9269	-1471.3494	550.2596	43.6792	3005.0084

HYPOTHESIS SUM OF PRODUCT MATRIX, $H=(ABC'-D)'(A(X'X)^{-1}A')^{-1}(ABC'-D)$

1	7.1630	-6.5336	1.7771	-4.1432	-1.5171	-7.5971	5.9946	2.2670
2	-6.5336	25.8966	-4.8964	2.4161	12.1080	10.2481	-16.8435	-21.3580
3	1.7771	-4.8964	1.1196	0.5635	-0.6354	-0.6184	3.2671	1.3955
4	-4.1432	2.4161	0.5635	15.7916	14.7638	21.7901	-3.5556	-22.7171
5	-1.5171	12.1080	-0.6354	14.7638	22.1574	22.7624	-8.3403	-35.8318
6	-7.5971	10.2481	-0.6184	21.7901	22.7624	31.9569	-9.3986	-35.7215
7	5.9946	-16.8435	3.2671	-3.5556	-8.3403	-9.3986	11.5638	14.3831
8	2.2670	-21.3580	1.3955	-22.7171	-35.8318	-35.7215	14.3831	58.2039

DETERMINANT(CEC') = .216343852559630+27 DETERMINANT(CEC'+H) = .232615807644990+27
U-STATISTIC = .930047929 DEGREES OF FREEDOM 8 3 316
F-STATISTIC = .946088135 DEGREES OF FREEDOM 24 897.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .51512456D-01
HECK'S THETA WITH PARAMETERS S,M,N 3 2.0 153.5 .489889170-01

OUTPUT FOR HYPOTHESIS NUMBER 4 (X,-X)B(I 0) PREDICTED VOLUMES SUBTOTALS

A MATRIX

1	1.0000	370.6000	38.7000	14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-1.0000	-370.6000	-38.7000	-14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	1.0000	317.8000	36.8000	11821.2000	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	-1.0000	-317.8000	-36.8000	-11821.2000	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	286.7000	36.9000	11215.8000
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	-286.7000	-36.9000	-11215.8000

C MATRIX

1	1.0000	1.0000	1.0000	1.0000	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	1.0000	1.0000	1.0000

D MATRIX

1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0

CONTRAST ABC'-D

1	10.2928	6.5268	-21.4315
2	5.2505	5.1968	-1.2291
3	12.5017	11.9328	-7.9221

CEC'

1	9412.1921	-127.2841	-4730.9457
2	-127.2841	5171.4389	-1707.7025
3	-4730.9457	-1707.7025	10452.1146

HYPOTHESIS SUM OF PRODUCT MATRIX, $H=(ABC'-D)'(A(X'X)^{-1}A')^{-1}(ABC'-D)$

1	28.3378	24.7193	-27.7273
2	24.7193	22.1574	-21.4098
3	-27.7273	-21.4098	40.2507

DETERMINANT(CEC') = 363331605918.09 DETERMINANT(CEC'+H) = 366811190320.20
U-STATISTIC = .990513921 DEGREES OF FREEDOM 3 3 316
F-STATISTIC = .333256364 DEGREES OF FREEDOM 9 764.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .7402B003D-02
HECK'S THETA WITH PARAMETERS S,4,N 3 -0.5 156.0 .73484016D-02

OUTPUT FOR HYPOTHESIS NUMBER 5 (X,-X)B1' PREDICTED VOLUMES TOTAL

A MATRIX

1	1.0000	370.6000	38.7000	14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-1.0000	-370.6000	-38.7000	-14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	1.0000	317.8000	36.8000	11821.2000	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	-1.0000	-317.8000	-36.8000	-11821.2000	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	286.7000	36.9000	11215.8000
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	-286.7000	-36.9000	-11215.8000

C MATRIX

1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

D MATRIX

1	0.0
2	0.0
3	0.0

CONTRAST ABC'-D

1	-4.6120
2	9.2182
3	16.5124

CEC'

111903.8812

HYPOTHESIS SUM OF PRODUCT MATRIX, H=(ABC'-D)'(A(X'X)$^{-1}$A')$^{-1}$(ABC'-D)

1	41.9102

DETERMINANT(CEC') = 11903.881158397 DETERMINANT(CEC'+H) = 11945.791400978
U-STATISTIC = .996491611 DEGREES OF FREEDOM 1 3 316
F-STATISTIC = .370851159 DEGREES OF FREEDOM 3 316.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .35207208D-02
HECK'S THETA WITH PARAMETERS S,M,N 1 0.5 157.0 .35083689D-02

OUTPUT FOR HYPOTHESIS NUMBER 6 (PX,-PX)BI WEIGHTED AVERAGE PREDICTED VOLUMES

A MATRIX

1	0.2286	84.7000	8.8000	3298.6000	0.3714	118.0000	13.7000	4390.4000	0.4000	115.9000	14.8000	4486.3000
	-0.2286	-84.7000	-8.8000	-3298.6000	-0.3714	-118.0000	-13.7000	-4390.4000	-0.4000	-115.9000	-14.8000	-4486.3000

C MATRIX

1	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	1.0000	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000

D MATRIX

1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CONTRAST ABC'-D

1	-2.2950	6.6620	-0.9013	5.7945	7.7268	9.6018	-5.0440	-12.7308

CEC'

1	1649.0874	269.5931	62.7336	-383.6756	-626.0576	-1082.1203	-65.0209	-324.8845
2	269.5931	1190.5657	-29.8625	180.3817	-377.8805	-449.3001	158.5044	-193.4195
3	62.7336	-29.8625	238.8058	-13.4237	34.2496	3.2713	-145.3985	-116.0362
4	-383.6756	180.3817	-13.4237	6162.2398	842.4044	-398.3343	-504.2802	-1613.9269
5	-626.0576	-377.8805	34.2496	842.4044	5171.4389	-195.9198	-40.4333	-1471.3494
6	-1082.1203	-449.3001	3.2713	-398.3343	-195.9198	5167.1467	-575.6476	550.2596
7	-65.0209	158.5044	-145.3985	-504.2802	-40.4333	-575.6476	2243.3772	43.6792
8	-324.8845	-193.4195	-116.0362	-1613.9269	-1471.3494	550.2596	43.6792	3005.0084

HYPOTHESIS SUM OF PRODUCT MATRIX, $H=(ABC'-D)'(A(X'X)^{-1}A')^{-1}(ABC'-D)$

1	1.5669	-4.5486	0.6154	-3.9563	-5.2756	-6.5558	3.4439	8.6922
2	-4.5486	13.2042	-1.7865	11.4846	15.3146	19.0308	-9.9973	-25.2325
3	0.6154	-1.7865	0.2417	-1.5538	-2.0720	-2.5748	1.3526	3.4138
4	-3.9563	11.4846	-1.5538	9.9890	13.3202	16.5525	-8.6953	-21.9465
5	-5.2756	15.3146	-2.0720	13.3202	17.7624	22.0725	-11.5951	-29.2654
6	-6.5558	19.0308	-2.5748	16.5525	22.0725	27.4285	-14.4087	-36.3668
7	3.4439	-9.9973	1.3526	-8.6953	-11.5951	-14.4087	7.5692	19.1042
8	8.6922	-25.2325	3.4138	-21.9465	-29.2654	-36.3668	19.1042	48.2179

DETERMINANT(CEC') = .21634385255963D+27 DETERMINANT(CEC'+H) = .22596525890724D+27
U-STATISTIC = .957420826 DEGREES OF FREEDOM 8 1 316
F-STATISTIC = 1.71776104 DEGREES OF FREEDOM 8 309.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .44472751D-01
HECK'S THETA WITH PARAMETERS S,M,N 1 3.0 153.5 .42579140D-01

OUTPUT FOR HYPOTHESIS NUMBER 7 (PX,-PX)B1' WEIGHTED AVERAGE PREDICTED VOLUMES TOTAL

A MATRIX

1	0.2286	84.7000	8.8000	3298.6000	0.3714	118.0000	13.7000	4390.4000	0.4000	115.9000	14.8000	4486.3000
	-0.2286	-84.7000	-8.8000	-3298.6000	-0.3714	-118.0000	-13.7000	-4390.4000	-0.4000	-115.9000	-14.8000	-4486.3000

C MATRIX

1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

D MATRIX

1	0.0

CONTRAST ABC'-D

1	8.8140

CEC'

111903.8812

HYPOTHESIS SUM OF PRODUCT MATRIX, $H=(ABC'-D)'(A(X'X)^{-1}A')^{-1}(ABC'-D)$

1	23.1125

DETERMINANT(CEC') = 11903.881158397 DETERMINANT(CEC'+H) = 11926.993629831
U-STATISTIC = .998062134 DEGREES OF FREEDOM 1 1 316
F-STATISTIC = .613554657 DEGREES OF FREEDOM 1 316.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .19415912D-02
HECK'S THETA WITH PARAMETERS S,M,N 1 -0.5 157.0 .19378288D-02

OUTPUT FOR HYPOTHESIS NUMBER 8 (X,-X)BV PREDICTED VALUE TOTAL

A MATRIX

1	1.0000	370.6000	38.7000	14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	-1.0000	-370.6000	-38.7000	-14435.8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	1.0000	317.8000	36.8000	11821.2000	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	-1.0000	-317.8000	-36.8000	-11821.2000	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	286.7000	36.9000	11215.8000
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0000	-286.7000	-36.9000	-11215.8000

C MATRIX

1	0.2451	0.2344	0.2217	0.1700	0.0996	0.0981	0.0887	0.0609

D MATRIX

1	0.0
2	0.0
3	0.0

CONTRAST ABC'-D

1	1.7108
2	1.3967
3	3.5186

CEC'

1	301.9434

HYPOTHESIS SUM OF PRODUCT MATRIX, H=(ABC'-D)'(A(X'X)$^{-1}$A')$^{-1}$(ABC'-D)

1	1.8250

DETERMINANT(CEC') = 301.94344595354 DETERMINANT(CEC'+H) = 303.76845448555
U-STATISTIC = .993992090 DEGREES OF FREEDOM 1 3 316
F-STATISTIC = .636657715 DEGREES OF FREEDOM 3 316.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .60442065D-02
HECK'S THETA WITH PARAMETERS S,M,N 1 0.5 157.0 .60078935D-02

OUTPUT FOR HYPOTHESIS NUMBER 9 (PX,-PX)BV WEIGHTED AVERAGE PREDICTED VALUE TOTAL

A MATRIX

1	0.2286	84.7000	8.8000	3298.6000	0.3714	118.0000	13.7000	4390.4000	0.4000	115.9000	14.8000	4486.3000
	-0.2286	-84.7000	-8.8000	-3298.6000	-0.3714	-118.0000	-13.7000	-4390.4000	-0.4000	-115.9000	-14.8000	-4486.3000

C MATRIX

1	0.2451	0.2344	0.2217	0.1700	0.0996	0.0981	0.0887	0.0609

D MATRIX

1	0.0

CONTRAST ABC'-D

1	2.2728

CEC'

1	301.9434

HYPOTHESIS SUM OF PRODUCT MATRIX, $H=(ABC'-D)'(A(X'X)^{-1}A')^{-1}(ABC'-D)$

1	1.5368

DETERMINANT(CEC') = 301.94344595354 DETERMINANT(CEC'+H) = 303.48027623389
U-STATISTIC = .994935930 DEGREES OF FREEDOM 1 1 316
F-STATISTIC = 1.60339081 DEGREES OF FREEDOM 1 316.
MAX CHARACTERISTIC ROOT OF H*(E INVERSE) .50897951D-02
HECK'S THETA WITH PARAMETERS S,M,N 1 -0.5 157.0 .506402030-02

Seegrist, Donald W.
1975. **A multivariate model and statistical method for validating tree grade lumber yield equations.** NE Forest Exp. Stn., Upper Darby, Pa.
20 p. (USDA Forest Serv. Res. Pap. NE-320)

Lumber yields within lumber grades can be described by a multivariate linear model. A method for validating lumber yield prediction equations when there are several tree grades is presented. The method is based on multivariate simultaneous test procedures.

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